NASA TECHNICAL NOTE

NASA TN D-2090

NASA TN D-2090

AERODYNAMIC AND CONTROL-SYSTEM CONTRIBUTIONS TO THE X-15 AIRPLANE LANDING-GEAR LOADS

by Richard B. Noll, Calvin R. Jarvis, Chris Pembo, Wilton P. Lock, and Betty J. Scott

Flight Research Center

Edwards, California

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D.C. • OCTOBER 1963

34 p.

N

TECHNICAL NOTE D-2090

AERODYNAMIC AND CONTROL-SYSTEM CONTRIBUTIONS TO THE X-15 AIRPLANE LANDING-GEAR LOADS

By Richard B. Noll, Calvin R. Jarvis, Chris Pembo,
Wilton P. Lock, and Betty J. Scott

Flight Research Center
Edwards, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-2090

AERODYNAMIC AND CONTROL-SYSTEM CONTRIBUTIONS TO THE X-15 AIRPLANE LANDING-GEAR LOADS

By Richard B. Noll, Calvin R. Jarvis, Chris Pembo, Wilton P. Lock, and Betty J. Scott

SUMMARY

Landing loads on the X-15 research airplane were investigated to determine the effects of the aerodynamic loads on the main-gear loads and of control-system inputs on the horizontal-tail aerodynamic loads. Study of the landing data indicated that conventional control-system inputs increase the down loads on the horizontal tail, which results in additional loads on the main gear. The following two methods were devised which effectively reduced the horizontal-tail deflections and the resulting landing-gear loads at touchdown: (1) automatically disengaging the stability augmentation system at main-gear touchdown and (2) reducing pilot inputs after main-gear touchdown. The data further indicate that landing without using flaps results in a down load on the wing during the second reaction, thus increasing the main-gear loads.

A review of the main-gear loads shows that the gear is satisfactory for typical landings but the loads may be excessive if the negative attitude of the airplane after nose-gear touchdown is increased.

INTRODUCTION

The X-15 airplane, unlike conventional aircraft, experiences a second reaction on the main gear at landing that is much more severe than the initial impact reaction. This is attributed to a combination of several factors: (1) the location of the main gear far rearward of the center of gravity and directly under the horizontal tail (ref. 1) so that aerodynamic down loads on the tail are transmitted to the main gear, (2) the uncontrolled pitch rotation about the main gear which abruptly reduces the wing lift, and (3) the high inertial loads of the airplane as it rotates back onto the main gear after nose-gear touchdown.

On several X-15 landings, the main-gear load has approached the ultimate limit. Previous studies of the landing dynamics of the aircraft (refs. 2 and 3) indicated that the severity of the main-gear second reaction could be reduced by minimizing the aerodynamic down loads on the horizontal tail after touchdown.

In order to assess the effects of the aerodynamic factors that contribute to the main-gear loads on the X-15 airplane, main-gear, horizontal-tail, and wing loads were measured during landings of the airplane. The control-system contribution to the aerodynamic loads on the horizontal tail during landings was also investigated. The results of these investigations are presented and discussed in this paper. Methods for reducing the loads are described, and data are presented from landings in which these methods were used.

SYMBOLS

F_s	main-gear shock-strut force, lb
F_t	horizontal-tail aerodynamic load, lb
F_v	main-gear vertical ground reaction, lb
K	SAS gain, surface deflection per rate input, deg/deg/sec
L_w	wing aerodynamic load, lb
q	pitching velocity, deg/sec
$\bar{q}$	dynamic pressure, lb/sq ft
Δt_n	time interval between initial main-gear contact and nose-gear contact, sec
V	indicated airspeed, knots
α	angle of attack, deg
δ_h	total horizontal-stabilizer deflection, positive when leading edge up, deg
$\delta_{h_{pilot}}$	horizontal-stabilizer deflection resulting from pilot command, deg
$\delta_{h_{SAS}}$	horizontal-stabilizer deflection commanded by the stability augmentation system, deg
θ	pitch-attitude angle, deg

AIRPLANE

The X-15 airplane and landing-gear system are described in detail in reference 3; physical characteristics are presented in table I. Briefly, the vehicle (figs. 1 and 2) is a rocket-powered research aircraft equipped with a landing-gear system consisting of a non-steerable full-castering nose gear located well forward of the airplane center of gravity and skid-type main gear located well to the rear under the tail. The unusual nature of the skid-type gear is shown by the sketch of the main gear in figure 3. The wing is equipped with conventional landing flaps.

The basic X-15 aerodynamic control system (ref. 4) is an irreversible hydraulic system. The horizontal control surfaces deflect asymmetrically for roll control and symmetrically for pitch control. Directional control is provided by upper and lower vertical stabilizers consisting of a fixed and a movable portion. All aerodynamic control surfaces are actuated by hydraulic actuators which are mechanically linked to the pilot's control stick. The horizontal surfaces are rate-limited at 26 degrees per second.

A stability augmentation system (SAS) was incorporated to improve the handling qualities of the basic airplane. A representative block diagram of the damping system and corresponding components is shown in figure 4. A detailed description of an X-15 stability augmentation system and its operating characteristics are presented in references 4 and 5. Basically, the system provides increased damping about all three airplane axes by sensing the rate of rotation about each axis and deflecting the control surfaces to produce a damping moment. The pilot and SAS commands are summed in a mechanical walking-beam arrangement to command the surface-actuator response. At any given instant the total surface deflection is the sum of pilot commands and augmentation-system commands, if the surfaces are not rate-limited.

INSTRUMENTATION AND DATA REDUCTION

The following pertinent quantities were recorded on NASA internal recording instruments which were synchronized by a common timer:

- Airspeed
- Angle of attack
- Pitch attitude
- Pitch rate
- Main-gear shock-strut force
- Horizontal-tail position
- Horizontal-tail aerodynamic load
- Wing aerodynamic load
- Longitudinal control-stick position
- SAS servo displacement

Airspeed and angle-of-attack data were obtained from the X-15 flow-direction sensor in the nose of the aircraft. Pitch rate, which ranged from -28 degrees per second to 28 degrees per second, was obtained by use of a rate gyro. The positions of the control surface, control stick, and SAS servo were measured by potentiometers.

The strain gages on the main-gear bellcrank arms were calibrated to yield the axial load on the shock-strut cylinder (fig. 3). The strain gages on the left and right horizontal-tail spindles and on the right wing spars and skin were calibrated to measure shear, bending moment, and torque at the root station of the respective surfaces. The loads on the surfaces were obtained by the method discussed in reference 6. A detailed description of the X-15 landing-gear instrumentation is given in reference 3.

To record the quantities being measured, standard galvanometer recording instruments were used which were synchronized at 0.1-second intervals to a common timer. The natural frequency and damping ratio of the recorders were 20 cps and 0.64, respectively. The natural frequencies of the gyro sensors were greater than 20 cps. Recordings were accurate within ±2 percent of the full-scale readings.

The horizontal-tail and wing loads were calculated by using wind-tunnel aerodynamic data which were presented as the variation of lift coefficient with angle of attack for flaps and gear up and for flaps and gear down in the presence of the ground plane. The X-15 angle of attack measured by airborne instruments is unreliable during landing; therefore, the measured airplane pitch-attitude angle is used.

RESULTS AND DISCUSSION

To determine the effect of the aerodynamic loads and the control-system contribution to the main-gear landing loads, 77 landings of the X-15 aircraft were reviewed. Similar piloting techniques were used on all of these landings; however, one landing was made without flaps as the result of a system malfunction. Because of insufficient data and similarity of landing conditions, not all of the investigated landings are discussed.

The X-15 landing approach is made at an indicated airspeed of approximately 300 knots. Immediately preceding the flare for touchdown, the flaps and gear are lowered. The touchdown occurs at an average airspeed of 188 knots with a sink rate of approximately 4 fps.

A summary of measured quantities from the landings is presented in tables II and III. Included are the maximum quantities for the first main-gear reaction and second main-gear reaction, as well as pretouchdown conditions including weight and sinking speed.

X-15 Landing Sequence

The influence of the main-gear location on the landing loads is shown by the schematic sketches of figure 5. Figure 5(a) indicates the down load on the main gear at touchdown produced by inertia and the negative horizontal-tail deflection required for landing. After the initial touchdown the airplane pitches down rapidly, since the horizontal tail, which is located over the main gear, offers no restraint on the rotation. As the airplane rotates onto the nose gear to a negative attitude, the down load on the horizontal tail is increased further and the lift on the wing is decreased (figs. 5(b) to 5(d)). In addition, inputs from the pilot and the stability augmentation system during the rotation onto the nose gear result in an increased horizontal-tail down load. Thus, the increased down load on the tail and the reduced up load on the wing, in combination with high inertial forces as the airplane rotates back onto the main gear after nose-gear impact (fig. 5(e)), result in a main-gear second reaction more severe than the reaction experienced during the initial touchdown.

Control-System Contribution to Horizontal-Tail Loads

The main-gear second reaction is shown for a typical landing in figure 6. A typical landing is one in which the down load on the horizontal tail increases to a maximum during nose-gear impact and the wing lift with flaps decreases abruptly as the airplane rotates onto the nose gear. The peak at 0.4 second indicates the first reaction of the main gear, which is caused primarily by the inertial loads at touchdown. The severity of the main-gear second reaction (maximum peak) is attributed to the combined loading conditions noted previously.

Immediately before touchdown, the pilot commands a leading-edge-down horizontal-surface deflection of 5.5° to maintain the desired angle of attack. Immediately following skid contact, the nose-down pitch rate is sensed by the SAS gyro which commands a surface deflection to oppose the pitch rate. Also, as the aircraft rotates downward, the pilot instinctively pulls back on the control stick in an attempt to reduce the nose-gear impact velocity.

The technique used to land the X-15 has little or no effect on the pitch rotation because of the relative locations of the main gear, the center of gravity, and the horizontal-stabilizer center of pressure. No moment about the airplane center of gravity is produced by deflecting the horizontal surfaces after the main gear is on the ground. The only significant result is the addition of a load on the main gear as a result of the downward-acting aerodynamic tail load.

The maximum surface deflection of -20° occurs approximately at nose-gear impact. Of this 20°, 16° was applied after main-gear touchdown. The maximum SAS command of 13° occurs at nose-gear impact. The surface deflection commanded by the pilot at nose-gear contact is approximately 10°. Because the surface actuator is functioning at its rate limit for a short period just prior to nose-gear touchdown, the total maximum surface deflection commanded by the pilot and the SAS is not obtained.

The maximum horizontal-stabilizer surface deflections from several X-15 landings are presented in figure 7. The surface deflection is shown as a function of the SAS gain and maximum pitch rate. The difference between the measured and the calculated data is an indication of pilot contribution to the horizontal-stabilizer deflections during the landings. The general trend of high surface deflection for correspondingly high SAS gains and pitch rates is apparent.

Figure 8 shows the relationship between the horizontal-stabilizer deflection and the resulting aerodynamic loading. These data represent the maximum value of aerodynamic loading on the horizontal tail at nose-gear touchdown. The calculations were made by using X-15 wind-tunnel data for the aircraft in a landing configuration (flaps and gear lowered in the presence of the ground plane). An angle of attack of 0° was used to conform with nose-gear touchdown.

As expected, the tail load increases with stabilizer deflection. By removing the surface deflections which occur after main-gear touchdown, the ratio of horizontal-tail load to dynamic pressure $\frac{F_t}{\bar{q}}$ could be reduced to about 35. The maximum total load on the main landing gear could be reduced if the control-system inputs causing the undesirable deflections were minimized.

Methods for Reducing Control-System Effects

The following two methods of reducing the control-system inputs during the landing were investigated:

(1) Automatically disengaging the stability augmentation system at main-gear touchdown.

(2) Avoiding or reversing the normal direction of the longitudinal control inputs by the pilot after initial touchdown.

A high-gain landing of the X-15 aircraft was made during which the pilot was instructed to push forward on the control stick immediately after main-gear contact. The stability augmentation system was also mechanized to automatically disengage at main-gear touchdown. The results of this landing are presented in figure 9. The tail load at initial touchdown is approximately the same as that required for a typical landing (fig. 6). During rotation following initial touchdown, the down load on the tail increased as in a typical landing. For this landing (fig. 9), the third peak in the shock-strut load is the main-gear second reaction. The airplane touched the ground lightly, skipped, and then achieved a solid touchdown, which resulted in two peaks in the initial touchdown data.

The stability augmentation system automatically disengaged at approximately 0.8 second after main-gear touchdown. Thus, there were no inputs from the system at the time of nose-gear impact. The data show that, immediately after main-gear touchdown, the pilot instinctively pulled back before he pushed forward on the control stick. He did, however, move the control stick forward fast enough so that the horizontal stabilizer reached a leading-edge-up deflection at nose-gear impact. Following nose-gear impact, the horizontal-tail load became an up load which decreased the main-gear second reaction to 34,700 pounds, compared with 43,300 pounds for a typical landing.

The upward component of aerodynamic load on the horizontal stabilizer after nose-gear impact was sufficiently large, combined with the stored energy in the compressed gear system, to momentarily lift the main gear off the ground. Although the main-gear lift-off was undesirable during this phase of the landing, the results showed that this method could reduce the tail loads.

On a subsequent landing, the pilot was requested to release the control stick following main-gear contact rather than to push forward. The results of this landing are presented in figure 10(a). The pilot inadvertently pulled back on the control stick before releasing it; thus, the surface deflection was not neutralized before nose-gear impact. The total surface deflection was, however, appreciably lower than is normal at nose-gear touchdown. On this landing, the stability augmentation system was automatically disengaged shortly after main-gear touchdown and the input to the horizontal surfaces was zero at nose-gear impact. The total surface deflection at nose-gear touchdown was only -4.5°, or approximately the same as before touchdown. This reduction is significant in comparison to the -20° deflection for the landing shown in figure 6. The maximum main-gear load for this flight is 36,000 pounds, compared to 43,300 pounds for a typical flight.

Figure 10(b) is a time history of a landing in which the pilot released the control stick at main-gear touchdown. The stability augmentation system was automatically disengaged, and very little input was made by the pilot after main-gear touchdown. The tail load was approximately 2,000 pounds less than the tail loads experienced at nose-gear touchdown in the typical landing shown in figure 6. This landing technique resulted in maximum main-gear loads of 35,500 pounds.

Data from these two landings (figs. 10(a) and 10(b)) show that gear loads can be lowered by reducing control-system inputs immediately following main-gear touchdown.

Effect of Wing Loads

Landing without the use of flaps decreases the angle of zero lift, which results in negative lift in the nose-down attitude; the increased landing speed associated with a no-flaps landing further increases the down loads on the wing. These two factors result in a net increase in main-gear load, which can be seen by comparing the data of figures 6 and 11. The wing lift for the no-flaps landing (fig. 11) followed a trend similar to that of a typical landing with flaps (fig. 6). The lift at touchdown, which is affected by the touchdown conditions (table III), is approximately the same for the two landings. The wing lift then decreases as the airplane rotates onto the nose gear. However, the wing lift for the no-flaps landing became a down load after nose-gear touchdown; whereas, the lift for the typical, or flaps landing, remained an up load. The down load on the wing for the no-flaps landing contributed to an increase in the main-gear second reaction, as indicated by a comparison of the shock-strut force of 66,500 pounds in figure 11 with that of 43,300 pounds in figure 6. The landing data after the time of maximum main-gear load are unreliable in figure 11, inasmuch as the ultimate load of the main gear was exceeded. It should be noted that the effect of wing lift on the main-gear load cannot be seen directly, since magnitudes and rates of increase of tail load were not identical.

Wing loads at maximum main-gear load are shown as a function of touchdown velocity in figure 12. The measured data are within an area bounded by the calculated curves for $\alpha = 0°$ and $\alpha = -4°$, which are representative of the X-15 airplane attitude at maximum main-gear load. Thus, the lift with flaps at maximum main-gear loads produces an up load which increases with velocity; whereas, a down load results if flaps are not used. If the attitude angle is decreased from -4° to -6° (as it would be if the lengths of the main-gear struts were increased), a wing down load results which would cause a more severe load on the main gear than experienced on the present configuration. For this attitude, the landing loads for a no-flaps condition would exceed the present landing-gear structural limits.

Main-Gear Loads

Maximum main-gear loads (second reaction) are shown as a function of touchdown velocity in figure 13 for 16 landings. The sum of the calculated tail and wing loads for these flights is presented for comparison. Also shown is the ultimate load for the present X-15 main gear. The main-gear loads for typical landings vary between 7,500 pounds and 10,200 pounds (open circles). For many landings, the main-gear loads approach the ultimate limit. The landing made without flaps (solid symbols) caused a negative lift on the wing at nose-gear impact. This, together with a large down load on the horizontal tail, resulted in a main-gear load of at least 11,500 pounds, which exceeded the main-gear ultimate load. The landings made with flaps (flagged circles) in which the control inputs were reduced resulted in the lowest main-gear loads experienced with the airplane. These reduced loads verify the importance of decreasing the aerodynamic forces affecting the landing-gear loads.

CONCLUSIONS

Landing loads on the X-15 research airplane were investigated to determine the effects of the aerodynamic loads on the main-gear loads and of control-system inputs on the horizontal-tail aerodynamic loads. The results of this investigation show that:

1. Conventional control-system inputs and resulting horizontal-tail loads which occurred after main-gear touchdown produced additional loads on the main landing gear.

2. The aerodynamic loading on the horizontal-tail surfaces was minimized by (a) automatically disengaging the stability augmentation system as the main gear came in contact with the ground and (b) minimizing the pilot's control input after main-gear touchdown.

3. When these revised landing methods were used, the maximum main-gear load was significantly reduced.

4. The main gear was satisfactory for landings in which flaps were used; however, loads were experienced that approached the main-gear ultimate load. Landing without flaps decreased the wing lift, thus greatly increasing the main-gear loads.

5. Any geometric change which increases the negative pitch attitude after nose-gear touchdown will result in increased main-gear loads which may exceed the present structural limits of the X-15 main gear.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., August 5, 1963.

REFERENCES

1. Houbolt, John C., and Batterson, Sidney A.: Some Landing Studies Pertinent to Glider-Reentry Vehicles. NASA TN D-448, 1960.

2. McKay, James M., and Kordes, Eldon E.: Landing Loads and Dynamics of the X-15 Airplane. NASA TM X-639, 1962.

3. McKay, James M., and Scott, Betty J.: Landing-Gear Behavior During Touchdown and Runout for 17 Landings of the X-15 Research Airplane. NASA TM X-518, 1961.

4. Tremant, Robert A.: Operational Experiences and Characteristics of the X-15 Flight Control System. NASA TN D-1402, 1962.

5. Taylor, Lawrence W., Jr., and Merrick, George B.: X-15 Airplane Stability Augmentation System. NASA TN D-1157, 1962.

6. Skopinski, T. H., Aiken, William S., Jr., and Huston, Wilber B.: Calibration of Strain-Gage Installations in Aircraft Structures for the Measurement of Flight Loads. NACA TN 2993, 1953.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE X-15 AIRPLANE

Wing:		
Airfoil section		NACA 66005 (modified)
Total area (includes 94.98 sq ft covered by fuselage), sq ft		200
Span, ft		22.36
Mean aerodynamic chord, ft		10.27
Root chord, ft		14.91
Tip chord, ft		2.98
Taper ratio		0.20
Aspect ratio		2.50
Sweep at 25-percent-chord line, deg		25.64
Incidence, deg		0
Dihedral, deg		0
Aerodynamic twist, deg		0
Flap -		
Type		Plain
Area (each), sq ft		8.30
Span (each), ft		4.50
Inboard chord, ft		2.61
Outboard chord, ft		1.08
	Original	Present
Deflection, down (nominal design), deg	40	32
Ratio flap chord to wing chord		0.22
Ratio total flap area to wing area		0.08
Ratio flap span to wing semispan		0.40
Trailing-edge angle, deg		5.67
Sweepback angle of hinge line, deg		0
Horizontal tail:		
Airfoil section		NACA 66005 (modified)
Total area (includes 63.29 sq ft covered by fuselage), sq ft		115.34
Span, ft		18.08
Mean aerodynamic chord, ft		7.05
Root chord, ft		10.22
Tip chord, ft		2.11
Taper ratio		0.21
Aspect ratio		2.83
Sweep at 25-percent-chord line, deg		45
Dihedral, deg		-15
Ratio horizontal-tail area to wing area		0.58
Movable surface area, sq ft		51.77
Deflection -		
Longitudinal, up, deg		15
Longitudinal, down, deg		35
Lateral differential (pilot authority), deg		±15
Lateral differential (autopilot authority), deg		±30
Control system		Irreversible hydraulic boost with artificial feel
Upper vertical tail:		
Airfoil section		10° single wedge
Total area, sq ft		40.91
Span, ft		4.58
Mean aerodynamic chord, ft		8.95
Root chord, ft		10.21
Tip chord, ft		7.56
Taper ratio		0.74
Aspect ratio		0.51
Sweep at 25-percent-chord line, deg		23.41

TABLE I.- PHYSICAL CHARACTERISTICS OF THE X-15 AIRPLANE - Concluded

Ratio vertical-tail area to wing area	0.20
Movable surface area, sq ft	26.45
Deflection, deg	±7.50
Sweepback of hinge line, deg	0
Control system	Irreversible hydraulic boost with artificial feel
Lower vertical tail:	
Airfoil section	10° single wedge
Total area, sq ft	34.41
Span, ft	3.83
Mean aerodynamic chord, ft	9.17
Root chord, ft	10.21
Tip chord, ft	8
Taper ratio	0.78
Aspect ratio	0.43
Sweep at 25-percent-chord line, deg	23.41
Ratio vertical-tail area to wing area	0.17
Movable surface area, sq ft	19.95
Deflection, deg	±7.50
Sweepback of hinge line, deg	0
Control system	Irreversible hydraulic boost with artificial feel
Fuselage:	
Length, ft	49.17
Maximum width, ft	7.33
Maximum depth, ft	4.67
Maximum depth over canopy, ft	4.97
Side area (total), sq ft	215.66
Fineness ratio	10.91

Main landing gear:		
Type	Two (6 in. wide, 3 ft long) skids	
Shock strut	Oleopneumatic (inside fuselage)	
	Original	Present
Strut inflation pressure, (fully extended), psi	750	1,200
Shock-strut stroke, in.	2.577	3.58
Tread distance (no load), ft	7.03	7.34

Nose landing gear:	
Tire type	VII
Tire size, in.	18 × 4.4
Ply rating	8
Rolling radius, in.	8
Wheels	Dual, corotating
Tire pressure, psi	185
Shock strut	Oleopneumatic
Shock-strut inflation pressure (fully extended), psi	184
Shock-strut stroke, in.	18
Moments of inertia (based on average landing weight of 14,500 lb):	
I_X, slug-ft^2	3,600
I_Y, slug-ft^2	83,500
I_Z, slug-ft^2	85,100
I_{XZ}, slug-ft^2	500

TABLE II.- SUMMARY OF TEST CONDITIONS AND MEASURED FORCES

(X-15-1)

Flight number (a)	Landing weight, lb	Vertical velocity, fps	Time of main-landing-gear impact, sec		Incremental vertical acceleration, g			First main-gear reaction: Maximum shock-strut force, lb		First main-gear reaction: Maximum shock-strut deflection, in.		Maximum main-gear tread, ft	Horizontal-tail load, lb (down)	Shock-strut pressure, psi (b)		Center-of-gravity position, percent mean aerodynamic chord
			Left	Right	Left	Right	Center of gravity	Left	Right	Left	Right			Left	Right	
1-1-5	13,234	2.0	0	--------	-----	2.7	0.6	--------	--------	--------	--------	9.48	--------	750	750	17.4
1-2-7	13,988	4.8	0	0.03	0.7	.9	.2	9,579	9,710	1.35	1.40	8.51	1,172	1,200	1,200	18.4
1-3-8	14,564	6.5	0.2	0	1.0	.8	--------	26,375	15,667	1.97	1.91	--------	1,171	1,200	1,200	--------
1-4-9	14,641	5.0	0	--------	-----	-----	--------	--------	--------	--------	--------	8.83	727	1,200	1,200	--------
1-5-10	14,610	4.5	0	--------	-----	-----	--------	--------	--------	--------	--------	--------	669	1,200	1,200	--------
1-6-11	14,233	1.0	0	.01	.5	.6	.6	6,203	5,957	.18	.11	7.69	1,156	1,200	1,200	--------
1-7-12	14,790	1.0	.20	0	.4	.8	.1	5,866	6,079	.10	.16	7.69	1,230	1,200	1,200	18.4
1-8-13	14,444	4.5	0	.01	.8	1.1	.5	9,368	9,425	1.26	.81	8.71	792	1,200	1,200	--------
1-9-17	14,838	2.0	0	.13	.4	.5	.4	6,203	6,487	--------	--------	7.70	--------	1,200	1,200	--------
1-10-19	14,318	1.5	0	0	.6	.8	.5	5,317	6,814	--------	--------	7.45	--------	1,200	1,200	--------
1-11-21	14,411	3.0	0	.05	.6	.6	.3	7,680	7,262	.76	--------	8.04	--------	1,200	1,200	--------
1-12-23	14,758	3.5	0	.01	.85	1.9	.5	7,891	8,038	.94	.77	8.30	--------	1,200	1,200	--------
1-13-25	14,859	4.5	0	0	.5	.7	.4	7,512	7,834	1.11	1.16	8.46	--------	1,200	1,200	--------
1-14-27	14,601	5.5	0	.005	.6	.7	.6	11,225	11,138	1.75	1.87	9.03	--------	1,200	1,200	--------
1-15-28	14,670	3.5	0	.01	.5	.6	.5	8,060	7,956	.88	.89	8.25	--------	1,200	1,200	--------
1-16-29	14,450	2.5	.07	0	.3	.4	.2	7,174	6,650	--------	--------	7.82	--------	1,200	1,200	--------
1-17-30	14,584	4.5	.01	0	.5	.6	.8	8,000	9,000	1.30	1.20	8.65	--------	1,200	1,200	--------
1-18-31	14,559	1.5	0	.06	.5	.5	.4	5,992	6,120	.18	.18	7.55	--------	1,200	1,200	--------
1-19-32	14,586	2.0	0	--------	-----	-----	--------	--------	--------	--------	--------	7.68	--------	1,200	1,200	--------
1-20-35	14,722	4.5	0	0	.8	.8	0	8,904	9,384	1.59	1.23	8.48	--------	1,200	1,200	--------
1-21-36	14,754	3.0	.025	0	.3	.6	.2	6,288	8,201	.30	.67	7.90	--------	1,200	1,200	--------
1-22-37	15,015	5.5	0	.03	.8	.6	.4	11,225	11,098	--------	--------	9.00	--------	1,200	1,200	17.7
1-23-39	14,997	0.5	0	--------	.5	.4	.2	--------	--------	--------	.18	7.58	--------	1,200	1,200	17.9
1-24-40	14,658	2.5	0	--------	.4	.2	--------	--------	--------	--------	--------	7.76	--------	1,200	1,200	15.8
1-25-44	14,515	5.5	0	.05	.5	-----	.3	13,542	12,816	--------	--------	9.1	--------	1,200	1,200	14.6
1-26-46	14,500	3.8	0	--------	-----	-----	--------	--------	--------	--------	--------	8.32	--------	1,200	1,200	17.9
1-27-48	14,574	--------	0	.01	1.6	-----	.7	12,387	9,943	--------	--------	9.02	--------	1,200	1,200	16.9
1-28-49	14,911	3.0	0	.07	.3	-----	.2	5,714	6,767	--------	--------	8.01	--------	1,200	1,200	17.0
1-29-50	14,924	1.5	0	.15	.2	-----	--------	5,062	5,862	--------	--------	7.44	--------	1,200	1,200	17.0
1-30-51	14,371	1.5	0	.05	.6	-----	--------	5,491	5,772	--------	--------	7.45	--------	1,200	1,200	17.1
1-31-52	14,573	3.0	0	.05	.8	-----	--------	5,478	5,320	--------	--------	7.97	--------	1,200	1,200	17.2
1-32-53	14,721	2.8	0	.20	.7	-----	--------	6,026	--------	--------	--------	7.88	--------	1,200	1,200	17.4

See footnotes at end of table, page 17.

TABLE II.- SUMMARY OF TEST CONDITIONS AND MEASURED FORCES - Continued

(X-15-1)

Second main-gear reaction

Flight number (a)	Nose-gear vertical velocity, fps	Time of nose-gear impact, sec	Incremental vertical acceleration, g				Maximum shock-strut force, lb		Maximum shock-strut deflection, in.			Maximum main-gear tread, ft	Maximum horizontal-tail load, lb (down)	Nose-gear shock-strut pressure, psi	Pitching velocity at nose-gear touchdown, radians/sec (down)	Distance from main-gear to nose-gear touchdown, ft	Runout distance, ft
			Left	Right	Nose	Center of gravity	Left	Right	Left	Right	Nose						
1-1-5	17.4	0.52	---	4.8	7.3	2.4	---	---	---	---	---	10.04	---	184	0.445	187	4,760
1-2-7	11.7	.73	1.6	1.7	9.8	.7	46,800	47,818	3.18	3.10	16.74	10.35	5,523	184	.300	247	6,531
1-3-8	12.6	.39	2.6	3.4	10.4	---	41,736	34,884	2.54	2.88	15.34	10.17	5,012	184	.323	194	7,228
1-4-9	13.7	.73	---	---	---	---	---	---	---	---	---	10.29	4,519	190	.350	266	4,714
1-5-10	15.4	.82	---	---	---	---	---	---	---	---	---	10.20	2,754	182	---	264	4,148
1-6-11	13.2	1.41	1.7	2.6	5.5	1.5	36,883	37,087	2.83	2.46	16.74	10.13	4,504	182	.338	497	4,920
1-7-12	12.6	1.34	1.6	2.3	9.6	1.2	43,339	40,229	3.08	2.89	17.70	10.25	4,765	180	.323	487	5,420
1-8-13	14.3	.96	2.3	2.6	9.9	---	38,613	36,598	2.82	2.65	15.90	10.13	4,643	180	.367	348	5,710
1-9-17	14.5	1.13	1.2	2.1	10,5	2.0	40,554	38,393	---	---	---	10.21	7,616	184	.371	401	5,280
1-10-19	11.4	1.45	.9	1.4	8.2	2.5	39,584	39,372	2.53	---	16.33	10.22	5,240	184	.292	541	5,940
1-11-21	9.2	.84	1.3	1.2	9.2	1.9	43,635	44,839	3.28	---	16.44	10.45	5,574	184	.236	333	6,388
1-12-23	12.6	1.00	2.1	2.1	12.3	2.0	41,947	38,597	3.02	3.10	16.15	10.21	5,732	184	.322	356	5,887
1-13-25	10.2	.72	.8	.9	5.8	2.0	39,288	39,127	2.94	3.13	16.83	10.19	3,168	184	.262	288	6,837
1-14-27	13.0	.64	1.3	1.0	7.6	2.7	37,727	38,066	2.80	3.03	16.86	10.05	2,632	184	.333	238	4,778
1-15-28	10.6	.81	1.3	1.3	10.6	1.6	44,774	44,635	3.10	3.32	16.97	10.42	---	184	.270	300	5,310
1-16-29	8.6	.78	1.9	1.4	---	1.9	42,706	39,046	2.95	3.01	16.58	10.17	6,697	184	.221	325	6,150
1-17-30	8.5	.59	.6	.7	3.5	2.3	35,954	42,881	2.43	2.74	15.82	9.99	4,865	184	.217	252	6,553
1-18-31	13.5	1.22	1.0	1.6	4.4	1.9	44,183	44,676	2.96	3.07	17.81	10.30	4,036	184	.346	414	4,646
1-19-32	---	---	---	---	---	---	---	---	---	---	---	10.25	---	184	---	387	6,300
1-20-35	8.5	.76	.9	.8	3.5	1.1	38,318	39,005	2.97	3.08	15.99	10.15	4,918	184	.216	312	7,600
1-21-36	12.9	.93	1.5	1.7	6.0	1.4	40,681	40,800	2.72	3.19	16.54	10.36	4,863	184	.331	333	5,781
1-22-37	13.6	.65	1.8	1.2	5.3	1.5	46,125	47,654	2.84	3.42	18.00	10.49	---	184	.348	253	5,230
1-23-39	10.9	.76	1.5	.9	4.4	1.5	---	---	---	3.36	18.00	10.40	---	184	.279	314	5,643
1-24-40	13.7	---	.7	1.7	4.7	1.9	---	---	---	---	17.50	10.45	---	184	.350	439	6,462
1-25-44	12.7	.60	3.0	---	3.7	1.7	51,888	49,764	---	---	---	10.64	7,272	184	.326	247	7,390
1-26-46	---	---	---	---	---	---	---	---	---	---	---	10.49	---	184	---	305	4,760
1-27-48	11.2	.84	2.7	---	4.8	3.2	44,245	41,465	---	---	---	10.39	6,065	184	.286	289	6,600
1-28-49	15.0	1.00	3.3	---	5.7	2.2	30,913	46,585	---	---	---	10.48	5,706	184	.383	377	5,810
1-29-50	13.1	1.35	2.1	---	2.8	1.6	42,649	44,311	---	---	---	10.40	6,008	184	.336	513	7,380
1-30-51	15.3	1.35	3.5	---	6.3	1.0	43,084	38,736	---	---	---	10.31	5,600	184	.391	478	5,550
1-31-52	---	1.47	1.2	---	4.8	---	46,039	45,529	---	---	---	10.45	7,637	184	---	220	5,810
1-32-53	8.0	1.12	3.0	---	6.1	---	40,800	32,334	---	---	---	10.28	---	184	.205	313	6,600

See footnotes at end of table, page 17.

TABLE II.- SUMMARY OF TEST CONDITIONS AND MEASURED FORCES - Continued

(X-15-2)

Flight number (a)	Landing weight, lb	Vertical velocity, fps	First main-gear reaction: Time of main-landing-gear impact, sec		Incremental vertical acceleration, g			Maximum shock-strut force, lb		Maximum shock-strut deflection, in.		Maximum main-gear tread, ft	Horizontal-tail load, lb (down)	Shock-strut pressure, psi (b)		Center-of-gravity position, percent mean aerodynamic chord
			Left	Right	Left	Right	Center of gravity	Left	Right	Left	Right			Left	Right	
[c]2-1-3	13,984	5.0 4.2	0	0.06	0.6 1.3	---	0.3	8,985 18,837	4,607 13,320	0.43 .67	0.35 .64	7.40	1,097	925	925	---
2-2-6	14,165	7.7	0	.03	1.9	---	.8	21,500	19,500	.59	.62	7.85	959	1,160	1,140	---
2-3-9	15,183	9.5	0	.005	2.6	---	1.4	26,300	26,700	1.68	1.58	8.79	1,664	1,200	1,200	17.3
2-4-11	15,062	6.5	0	.03	1.8	2.2	.8	27,605	28,634	1.89	2.07	9.42	1,639	1,200	1,200	19.3
2-5-12	14,798	3.6	0	.14	.9	.5	.2	6,999	6,324	1.04	.66	8.23	976	1,200	1,200	---
2-6-13	14,619	2.5	0	.16	.3	.3	.2	6,960	7,139	.94	1.04	7.88	1,102	1,200	1,200	19.1
2-7-15	14,394	2.5	0	.08	.8	.3	---	5,122	5,975	.10	.15	7.79	1,132	1,200	1,200	19.4
2-8-16	14,583	3.5	0	.07	1.3	.5	.4	8,133	7,566	1.12	.44	8.11	1,399	1,200	1,200	19.3
2-9-18	14,469	4.0	0	.05	.6	.6	---	6,960	6,440	.83	.52	8.09	---	1,200	1,200	18.9
2-10-21	14,419	5.0	0	.078	---	---	.2	9,110	8,769	1.23	.92	8.69	---	1,200	1,200	15.1
2-11-22	14,486	4.5	0	.093	---	---	.4	8,563	6,441	1.02	---	8.56	---	1,200	1,200	14.9
2-12-23	14,381	5.5	0	.090	.7	.5	.2	7,976	7,915	1.48	---	---	---	1,200	1,200	15.0
2-13-26	14,501	4.0	0	.040	---	---	.5	8,289	9,040	.82	---	8.35	---	1,200	1,200	12.6
2-14-28	14,741	2.9	0	---	---	---	---	---	---	---	---	7.95	---	1,200	1,200	14.1
2-15-29	14,447	3.7	0	.020	---	---	.6	7,234	8,458	1.51	1.34	8.26	---	1,200	1,200	12.2
2-16-31	14,567	2.3	0	.283	---	---	.3	8,641	8,186	.61	---	7.70	---	1,200	1,200	14.6
2-17-33	14,845	5.0	.10	0	.9	1.1	.6	---	---	1.49	---	8.80	---	1,200	1,200	12.7
2-18-34	14,610	2.8	0	.12	.5	.4	.2	5,709	6,286	.53	---	7.90	---	1,200	1,200	12.6
2-19-35	14,654	2.5	0	.10	.5	.4	.4	6,412	6,518	.60	---	7.76	---	1,200	1,200	13.7
2-20-36	14,692	2.0	0	.01	.3	.1	.1	5,435	3,686	.14	---	7.60	---	1,200	1,200	14.8
2-21-37	14,600	4.5	0	---	.4	.4	0	---	---	1.35	---	8.55	---	1,200	1,200	13.6
2-22-40	14,891	0.5	.08	0	---	---	---	5,474	5,902	---	---	---	---	1,200	1,200	15.7
2-23-43	14,968	2.2	.03	0	.2	---	.2	5,865	4,030	---	---	7.66	---	1,200	1,200	15.9
2-24-44	15,055	4.1	.03	0	2.0	---	.5	6,934	7,935	---	---	8.47	---	1,200	1,200	15.9
2-25-45	14,960	1.8	.03	0	1.7	---	.6	5,865	4,030	---	---	7.53	---	1,200	1,200	16.0
2-26-46	15,091	1.8	.01	0	1.8	---	.1	5,748	3,463	---	---	7.53	---	1,200	1,200	16.2
2-27-47	15,021	2.3	0	.15	.4	---	.1	6,219	6,528	---	---	7.68	---	1,200	1,200	16.0
2-28-48	14,983	2.2	.08	0	3.2	---	1.1	8,993	10,088	---	---	7.67	---	1,200	1,200	15.9
2-29-50	15,102	---	0	.03	2.0	---	1.2	7,781	6,674	---	---	---	---	1,200	1,200	17.0
2-30-51	14,953	4.0	0	.04	.9	---	.7	11,612	11,174	---	---	8.25	---	1,200	1,200	15.5
2-31-52	15,982	3.9	.005	0	1.2	---	.4	26,900	23,650	---	---	---	740 up	1,200	1,200	18.6

See footnotes at end of table, page 17.

TABLE II.- SUMMARY OF TEST CONDITIONS AND MEASURED FORCES - Continued

(X-15-2)

			Second main-gear reaction																
Flight number (a)	Nose-gear vertical velocity, fps	Time of nose-gear impact, sec	Incremental vertical acceleration, g				Maximum shock-strut force, lb		Maximum shock-strut deflection, in.			Maximum main-gear tread, ft	Maximum horizontal-tail load, lb (down)	Nose-gear shock-strut pressure, psi	Pitching velocity at nose-gear touchdown, radians/sec (down)	Maximum nose-gear reaction, lb		Distance from main-gear to nose-gear touchdown, ft	Runout distance, ft
			Left	Right	Nose	Center of gravity	Left	Right	Left	Right	Nose					Vertical	Spin-up drag (d)		
2-1-3	13.2	0.85	1.7	----	----	1.3	35,071	37,407	2.57	2.58	----	9.50	6,434	184	0.337	----	----	330	5,560
2-2-6	12.1	.51	3.5	----	----	3.0	34,500	35,750	2.42	2.34	18.00	9.38	4,638	184	.309	----	----	203	4,252
2-3-9	16.5	.59	2.2	----	6.3	4.3	35,200	34,500	2.59	2.41	18.00	9.21	5,448	184	.422	----	----	184	1,561
2-4-11	12.3	.46	2.4	2.8	7.3	1.6	40,664	43,301	2.90	3.20	17.29	10.25	4,758	175	.315	15,854	9,870	184	5,734
2-5-12	12.6	.95	4.1	4.0	9.1	1.7	40,400	40,400	2.98	2.93	15.83	10.23	5,039	330	.323	19,789	10,580	332	4,669
2-6-13	7.8	.93	1.9	1.7	6.8	1.3	37,106	35,580	2.77	2.67	16.46	9.96	5,308	178	.200	14,029	8,430	355	6,073
2-7-15	12.6	.98	2.4	2.3	10.5	----	36,324	37,908	2.73	2.74	16.31	10.10	5,632	184	.323	15,708	12,900	357	5,938
2-8-16	7.6	.80	2.6	1.6	9.2	1.9	44,457	46,482	3.26	3.04	17.41	10.36	5,134	184	.195	16,764	15,040	297	5,625
2-9-18	16.0	1.10	2.3	2.1	13.1	----	37,106	36,278	2.77	2.87	17.65	10.14	----	184	.410	25,394	----	339	4,330
2-10-21	24.5	.97	----	----	----	2.0	38,944	44,465	2.78	2.89	16.14	10.34	----	184	.630	22,935	15,369	308	5,042
2-11-22	15.8	.74	----	----	----	4.9	39,100	41,632	2.71	3.02	16.65	10.19	----	184	.403	16,300	----	284	6,574
2-12-23	16.4	.68	1.1	1.1	7.2	1.3	41,329	41,788	2.82	3.02	16.80	10.22	----	184	.420	18,117	----	271	6,600
2-13-26	14.4	.90	----	----	8.2	3.1	41,407	45,163	3.20	----	17.27	10.23	4,594	184	.368	21,260	----	316	5,340
2-14-28	----	----										10.19		184	----			360	6,531
2-15-29	10.6	.76	----	----	9.6	2.1	42,228	48,810	----	----	16.70	10.40	----	184	.272	19,980	----	259	3,778
2-16-31	10.8	1.02	----	----		3.1	41,563	48,461	3.12	----	----	10.29	4,380	184	.276	----	----	385	6,761
2-17-33	13.4	.80	1.6	1.6	----	3.2	----	----	3.45	----	16.88	10.45	----	184	.343	----	----	276	4,646
2-18-34	12.9	1.01	1.6	2.5	6.1	1.8	40,820	42,486	3.25	----	16.12	10.39	----	184	.330	----	----	373	4,490
2-19-35	14.7	1.28	1.1	1.5	6.8	2.4	42,658	47,103	3.34	----	16.61	10.44	----	184	.376	----	----	410	4,418
2-20-36	14.3	1.22	1.2	1.9	6.8	2.4	42,736	44,620	3.26	----	----	10.39	----	184	.366	----	----	410	4,325
2-21-37	14.3	.91	1.4	1.8	7.1	1.2	----	----	3.42	----	----	10.45	----	184	.366	----	----	315	5,280
2-22-40	15.4	1.26	2.0	----	6.9	2.5	42,867	45,249	----	----	----	10.41	5,982	184	.395	----	----	436	5,800
2-23-43	14.5	1.16	2.9	----	3.3	2.8	40,777	43,930	----	----	----	10.46	4,016	184	.370	----	----	387	5,810
2-24-44	8.8	.79	----	----	9.2	5.4	44,980	44,855	----	----	----	10.46	3,340	184	.226	----	----	290	5,820
2-25-45	13.0	1.35	----	----	----	3.1	35,581	39,964	----	----	----	10.32	1,464	184	.334	----	----	492	7,150
2-26-46	14.1	1.10	3.0	----	7.0	2.9	43,426	44,362	----	----	----	10.51	3,630	184	.361	----	----	376	4,580
2-27-47	15.7	1.20	1.5	----	9.3	3.6	42,499	44,229	----	----	----	10.44	----	184	.401	----	----	349	5,020
2-28-48	----	.83	3.3	----	11.3	3.9	39,882	41,904	----	----	----	10.42	----	184	----	----	----	349	6,600
2-29-50	----	.95	3.2	----	7.0	4.1	35,229	38,994	----	----	----	----	4,440	184	----	----	----	278	6,870
2-30-51	----	.76	3.1	----	5.7	----	34,955	40,390	----	----	----	10.46	7,260	184	----	----	----	494	6,340
2-31-52	----	.71	----	----	3.2	3.0	50,900	67,600	----	----	----	----	7,702	184	----	----	----	340	----

See footnotes at end of table, page 17.

TABLE II.- SUMMARY OF TEST CONDITIONS AND MEASURED FORCES - Continued

(X-15-3)

Flight number (a)	Landing weight, lb	Vertical velocity, fps	Time of main-landing-gear impact, sec		Incremental vertical acceleration, g			First main-gear reaction: Maximum shock-strut force, lb		Maximum shock-strut deflection, in. (e)		Maximum main-gear tread, ft	Horizontal-tail load, lb (down)	Shock-strut pressure, psi (b)		Center-of-gravity position, percent mean aerodynamic chord
			Left	Right	Left	Right	Center of gravity	Left	Right	Left	Right			Left	Right	
3-1-2	14,723	2.0	.16	0	.2	.1	---	6,912	6,344	---	---	7.57	---	1,200	1,200	17.2
3-2-3	14,303	2.5	0	.05	---	---	.8	6,112	3,976	---	---	7.87	---	1,200	1,200	14.1
3-3-7	14,307	2.5	---	---	---	---	---	8,702	6,617	---	---	---	---	1,200	1,200	15.8
3-4-8	14,286	7.3	---	---	---	---	---	---	---	---	---	9.72	---	1,200	1,200	14.3
3-5-9	14,653	1.0	.05	0	.4	---	1.5	6,075	4,252	---	---	---	---	1,200	1,200	16.3
3-6-10	14,553	6.2	0	.02	1.9	---	1.5	20,763	21,270	---	---	9.30	---	1,200	1,200	16.5
3-7-14	14,420	3.0	0	.06	1.0	---	2.7	7,015	6,521	---	---	8.16	---	1,200	1,200	14.9
3-8-16	14,558	---	0	.15	.2	---	.2	4,661	2,783	---	---	---	---	1,200	1,200	16.2
3-9-18	14,246	4.0	0	.08	.5	---	2.1	7,678	7,122	---	---	8.40	---	1,200	1,200	16.0
3-10-19	14,492	6.8	.08	0	.9	---	.9	6,276	7,783	---	---	9.52	---	1,200	1,200	17.0
3-11-20	14,441	0.5	0	.03	.5	---	.4	5,059	5,243	---	---	---	---	1,200	1,200	16.9
3-12-22	14,491	2.4	.04	0	.7	---	1.1	5,813	6,104	---	---	---	4,762	1,200	1,200	16.9
3-13-23	14,562	3.0	0	.20	.4	---	.2	5,666	910	---	---	---	5,991	1,200	1,200	19.1
3-14-24	14,709	2.0	0	.07	.2	---	.1	5,425	5,594	---	---	7.59	5,069	1,200	1,200	---

See footnotes at end of table, page 17.

TABLE II.- SUMMARY OF TEST CONDITIONS AND MEASURED FORCES - Concluded

(X-15-3)

Flight number (a)	Nose-gear vertical velocity, fps	Time of nose-gear impact, sec	Second main-gear reaction: Incremental vertical acceleration, g				Maximum shock-strut force, lb		Maximum shock-strut deflection, in. (e)			Maximum main-gear tread, ft	Maximum horizontal-tail load, lb (down)	Nose-gear shock-strut pressure, psi	Pitching velocity at nose-gear touchdown, radians/sec (down)	Distance from main-gear to nose-gear touchdown, ft	Runout distance, ft
			Left	Right	Nose	Center of gravity	Left	Right	Left	Right	Nose						
3-1-2	9.3	1.16	2.3	2.0	6.2	2.4	46,671	44,406	-----	-----	-----	10.16	-----	184	0.238	384	6,200
3-2-3	10.2	1.36	4.1	-----	9.1	2.3	36,872	45,461	-----	-----	-----	9.90	-----	184	.262	319	6,340
3-3-7	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	10.26	-----	184	-----	365	6,450
3-4-8	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	10.44	-----	184	-----	196	5,104
3-5-9	9.1	1.35	2.9	-----	6.2	2.8	42,024	40,147	-----	-----	-----	10.25	5,546	184	.234	452	5,810
3-6-10	8.0	.81	3.0	-----	14.1	4.6	41,125	40,553	-----	-----	-----	10.25	4,553	184	.206	261	5,280
3-7-14	10.2	.88	1.0	-----	3.6	4.1	41,012	36,825	-----	-----	-----	10.26	-----	184	.261	338	5,030
3-8-16	8.3	1.85	1.1	-----	4.4	1.7	42,078	38,968	-----	-----	-----	-----	6,939	184	.213	-----	-----
3-9-18	11.8	.84	1.5	-----	12.3	3.4	40,658	40,425	-----	-----	-----	10.34	6,601	184	.303	303	5,280
3-10-19	12.7	1.08	4.0	-----	14.2	2.7	46,266	44,672	-----	-----	-----	10.45	-----	184	.325	180	-----
3-11-20	9.3	1.06	1.1	-----	4.9	2.6	40,338	38,903	-----	-----	-----	10.33	8,534	184	.238	438	7,920
3-12-22	11.7	1.42	2.2	-----	11.7	2.8	34,813	33,640	-----	-----	-----	9.60	1,331	184	.299	510	7,286
3-13-23	10.4	1.41	.9	-----	3.1	2.0	36,965	35,990	-----	-----	-----	9.76	3,754	184	.267	498	7,400
3-14-24	8.0	1.04	.5	-----	2.7	3.0	33,363	35,845	-----	-----	-----	9.74	4,793	184	.205	393	7,392

[a]First term indicates X-15 airplane by number; second term indicates number of free flights for that airplane; third term indicates number of airplane X-15/B-52 missions for the airplane.

[b]Serviced to ±10 psi.

[c]Initial contact followed by rebound.

[d]Incremental drag force.

[e]Not measured on X-15-3.

TABLE III.- PRETOUCHDOWN CONDITIONS

(X-15-1)

Flight number (a)	Pilot	Landing weight, lb	Wind conditions: Velocity, knots	Wind conditions: Direction	Velocity at touchdown, KIAS	Vertical velocity, fps	True ground speed at touchdown, knots	Runway: Magnetic heading, deg	Runway: Condition	Indicated angle of attack, deg	Pitch velocity, radians/sec	Roll velocity, radians/sec	Sideslip angle, deg	Flap angle, deg	Center-of-gravity acceleration, g
1-1-5	A	13,324	Calm[b]	---	153	2.0	168	350	Dry, hard	8.5	0.024 (down)	0.091 (right)	0.7 (left)	38.0	1.40
1-2-7	A	13,988	Calm	West	189	4.8	168	180	Damp, hard	7.1	.004 (down)	.012 (right)	.7 (right)	38.0	1.20
1-3-8	B	14,564	21	Southwest	214	6.5	238	350	Dry, hard	4.7	.025 (down)	.025 (left)	1.6 (left)	41.9	1.20
1-4-9	C	14,641	Calm	---	174	5.0	184	350	Dry, hard	7.6	.022 (up)	.005 (left)	.1 (right)	42.3	---
1-5-10	B	14,610	18	Southwest	180	4.5	163	250	Dry, hard	7.5	---	---	---	42.5	---
1-6-11	C	14,233	Calm	North	189	1.0	192	350	Dry, hard	7.4	.019 (up)	.060 (right)	.2 (left)	28.5	1.10
1-7-12	B	14,790	23	West-southwest	193	1.0	198	180	Dry, hard	5.2	.018 (down)	.066 (right)	.94 (right)	28.7	.95
1-8-13	C	14,444	19	North-northeast	173	4.5	190	180	Dry, hard	7.7	.048 (up)	.019 (left)	.32 (left)	29.6	1.0
1-9-17	B	14,838	7	South	185	2.0	190	180	Dry, hard	7.3	.009 (down)	.020 (right)	1.70 (right)	---	.95
1-10-19	C	14,318	4	South	198	1.5	205	180	Dry, hard	6.1	.027 (up)	.005 (right)	1.25 (right)	29.1	1.01
1-11-21	B	14,411	Calm	---	192	3.0	207	180	Dry, hard	5.7	.005 (down)	.001 (right)	2.77 (right)	25.1	.86
1-12-23	C	14,758	Calm	Southwest	181	3.5	188	180	Dry, hard	7.0	.055 (up)	.180 (left)	---	29.7	---
1-13-25	D	14,859	Calm	---	196	4.5	205	180	Dry, hard	5.7	.012 (up)	.037 (right)	0	---	1.01
1-14-27	D	14,601	5	East	180	5.5	185	350	Dry, hard	6.9	.009 (down)	.010 (right)	---	29.1	.94
1-15-28	E	14,670	Calm	---	182	3.5	191	350	Dry, hard	7.9	.023 (up)	0	.20 (right)	29.4	1.16
1-16-29	F	14,450	19	East-northeast	195	2.5	216	350	Dry, hard	5.4	.037 (down)	.010 (right)	.35 (left)	28.7	.99
1-17-30	F	14,584	Calm	North	209	4.5	212	350	Dry, hard	4.4	.012 (down)	---	---	28.2	.99
1-18-31	G	14,559	Calm	---	176	1.5	182	180	Damp, hard	7.3	.005 (up)	.035 (right)	.90 (right)	28.2	.98
1-19-32	G	14,586	4	East	---	2.0	---	180	Damp, hard	---	---	---	---	---	---
1-20-35	E	14,722	Calm	South	210	4.5	212	180	Dry, hard	9.8	.018 (up)	.020 (right)	.80 (left)	29.4	1.05
1-21-36	C	14,754	5	Northeast	183	3.0	187	180	Dry, hard	13.1	.004 (up)	.010 (left)	1.60 (left)	25.9	.80
1-22-37	D	15,015	12	Southwest	196	5.5	195	180	Damp, hard	10.0	.007 (up)	.020 (right)	1.50 (left)	30.0	.69
1-23-39	F	14,997	Calm	North-northeast	204	.5	213	180	Damp, hard	7.7	.014 (up)	.003 (left)	.50 (right)	---	.89
1-24-40	B	14,658	Calm	---	---	2.5	---	180	Damp, hard	11.7	.023 (down)	.060 (right)	2.80 (right)	29.63	1.03
1-25-44	D	15,515	7	East	---	5.5	205	Mud Lake landing[c]	Dry, rough	6.2	.006 (down)	---	.7 (left)	27.6	.89
1-26-46	B	14,500	8	Southwest	190	3.8	---	180	Dry, hard	---	---	---	---	---	---
1-27-48	B	14,574	Calm	---	---	---	176	180	Dry, hard	---	.053 (up)	.12 (left)	.15 (right)	30.5	.63
1-28-49	F	14,911	Calm	---	187	3.0	187	180	Dry, hard	6.8	.020 (down)	.014 (right)	.2 (left)	27.8	1.14
1-29-50	B	14,924	Calm	Southwest	208	1.5	208	180	Dry, hard	6.1	.002 (up)	.014 (right)	2.5 (right)	---	.96
1-30-51	B	14,371	Calm	---	192	1.5	192	180	Dry, hard	7.4	.012 (up)	.069 (left)	1.8 (right)	31.8	.98
1-31-52	B	14,573	Calm	---	210	3.0	---	180	Dry, hard	---	.026 (up)	.015 (right)	---	24.4	---
1-32-53	G	14,721	Calm	---	164	2.8	145	180	Dry, hard	8.5	.006 (down)	.016 (left)	1.3 (right)	24.2	1.00

See footnotes at end of table, page 20.

TABLE III.- PRETOUCHDOWN CONDITIONS - Continued

(X-15-2)

Flight number (a)	Pilot	Landing weight, lb	Wind conditions: Velocity, knots	Wind conditions: Direction	Velocity at touchdown, KIAS	Vertical velocity, fps	True ground speed at touchdown, knots	Runway: Magnetic heading, deg	Runway: Condition	Indicated angle of attack, deg	Pitch velocity, radians/sec	Roll velocity, radians/sec	Sideslip angle, deg	Flap angle, deg	Center-of-gravity acceleration, g
[d]2-1-3	A	13,984	9	Southwest	184	5.0, 4.2	203	350	Dry, hard	8.1	0.045 (up)	0.013 (right)	0.88 (left)	23.2	1.15
2-2-6	A	14,165	Calm[b]	Northwest	180	7.7	191	350	Dry, hard	7.6	.047 (down)	.020 (right)	.49 (left)	37.6	1.08
2-3-9	A	15,183	18	Northwest	161	9.5	145	Rosamond Dry Lake[c]	Dry, hard	10.8	.036 (up)	.008 (left	3.2 (left)	37.2	.85
2-4-11	A	15,062	4	Southwest	188	6.5	185	350	Dry, hard	6.2	.008 (up)	.056 (left)	1.2 (left)	33.8	1.00
2-5-12	A	14,798	Calm	----------	185	3.6	183	180	Dry, hard	8.7	.006 (up)	.020 (left)	.44 (left)	32.3	1.25
2-6-13	A	14,619	9	North-northeast	192	2.5	201	180	Dry, hard	6.3	.003 (down)	.032 (right)	1.5 (left)	33.8	1.25
2-7-15	A	14,394	Calm	North-northeast	193	2.5	193	180	Dry, hard	7.1	.013 (up)	.048 (right)	.1 (right)	31.5	1.05
2-8-16	A	14,583	Calm	----------	185	3.5	198	180	Dry, hard	6.6	.021 (up)	.012 (left)	.15 (right)	27.2	.95
2-9-18	A	14,469	Calm	Southeast	160	4.0	161	180	Dry, hard	11.2	.016 (down)	.005 (right)	.50 (right)	26.5	1.10
2-10-21	A	14,419	5	Northeast	156	5.0	165	180	Dry, hard	10.7	.002 (up)	.050 (right)	.2 (right)	29.7	1.09
2-11-22	A	14,486	Calm	----------	187	4.5	196	180	Dry, hard	6.0	.004 (down)	.062 (right)	.9 (left)	28.1	1.04
2-12-23	A	14,381	17	Northeast	181	5.5	203	180	Dry, hard	6.4	.040 (down)	0	----------	27.5	1.01
2-13-26	C	14,501	10	North-northeast	180	4.0	182	180	Dry, hard	13.1	.021 (up)	.015 (left)	----------	26.8	1.08
2-14-28	B	14,871	Calm	Southeast	----------	2.9	----------	180	Dry, hard	----------	----------	----------	----------	----------	----------
2-15-29	C	14,447	20	West-southwest	189	3.7	171	230	Dry, hard	6.9	.013 (up)	.045 (right)	----------	27.1	.92
2-16-31	B	14,567	Calm	East	189	2.3	201	180	Dry, hard	10.2	.028 (up)	.006 (right)	5.35 (left)	28.7	1.05
2-17-33	C	14,945	14	South-southwest	180	5.0	175	180	Dry, hard	15.0	.034 (up)	.190 (left)	1.6 (left)	29.5	----------
2-18-34	B	14,610	10	South-southwest	186	2.8	196	180	Dry, hard	10.5	.013 (up)	0	2.35 (left)	31.4	1.03
2-19-35	D	14,654	9	South-southwest	179	2.5	171	180	Dry, hard	12.5	.011 (up)	0	2.25 (left)	31.6	1.03
2-20-36	C	14,692	7	South	175	2.0	180	180	Dry, hard	13.5	.001 (down)	.004 (right)	.2 (right)	32.1	----------
2-21-37	C	14,600	Calm	South	179	4.5	179	180	Dry, hard	15.7	.015 (up)	.030 (right)		32.1	1.28
2-22-40	F	14,891	11	West	196	.5	202	180	Dry, hard	7.2	.002 (up)	.023 (left)	1.2 (left)	30.4	.98
2-23-43	C	14,968	Calm	----------	184	2.2	178	180	Dry, hard	----------	.026 (down)	.076 (right)	----------	29.7	1.02
2-24-44	E	14,959	9	Southwest	191	4.1	188	180	Dry, rough	8.0	.040 (up)	.019 (right)	.4 (right)	30.0	1.05
2-25-45	E	14,960	Calm	----------	195	1.8	198	180	Dry, hard	6.5	.063 (up)	.040 (right)	.1 (right)	29.2	1.60
2-26-46	F	15,091	10	South	175	1.8	181	180	Dry, hard	7.8	.005 (up)	.08 (right)	.4 (right)	30.4	.95
2-27-47	F	15,021	Calm	----------	181	2.3	175	180	Dry, hard	8.0	.012 (down)	.038 (left)	1.2 (right)	29.7	1.05
2-28-48	F	14,983	18 to 26	Southwest	200	2.2	----------	180	Dry, hard	5.3	.035 (down)	.036 (right)	1.1 (left)	28.9	1.00
2-29-50	E	15,102	Calm	----------	187	----------	----------	180	Dry, hard	7.2	.034 (up)	.035 (left)	.5 (left)	28.6	1.23
2-30-51	E	14,953	Calm	----------	173	4.0	186	180	Dry, rough	5.7	.004 (down)	.030 (right)	.6 (left)	30.0	.95
2-31-52	E	15,982	4	Southeast	256	3.9	251	Mud Lake landing[c]	Dry, hard	7.4	.026 (up)	.007 (right)	.4 (right)	0	1.02

See footnotes at end of table, page 20.

TABLE III.- PRETOUCHDOWN CONDITIONS - Concluded

(X-15-3)

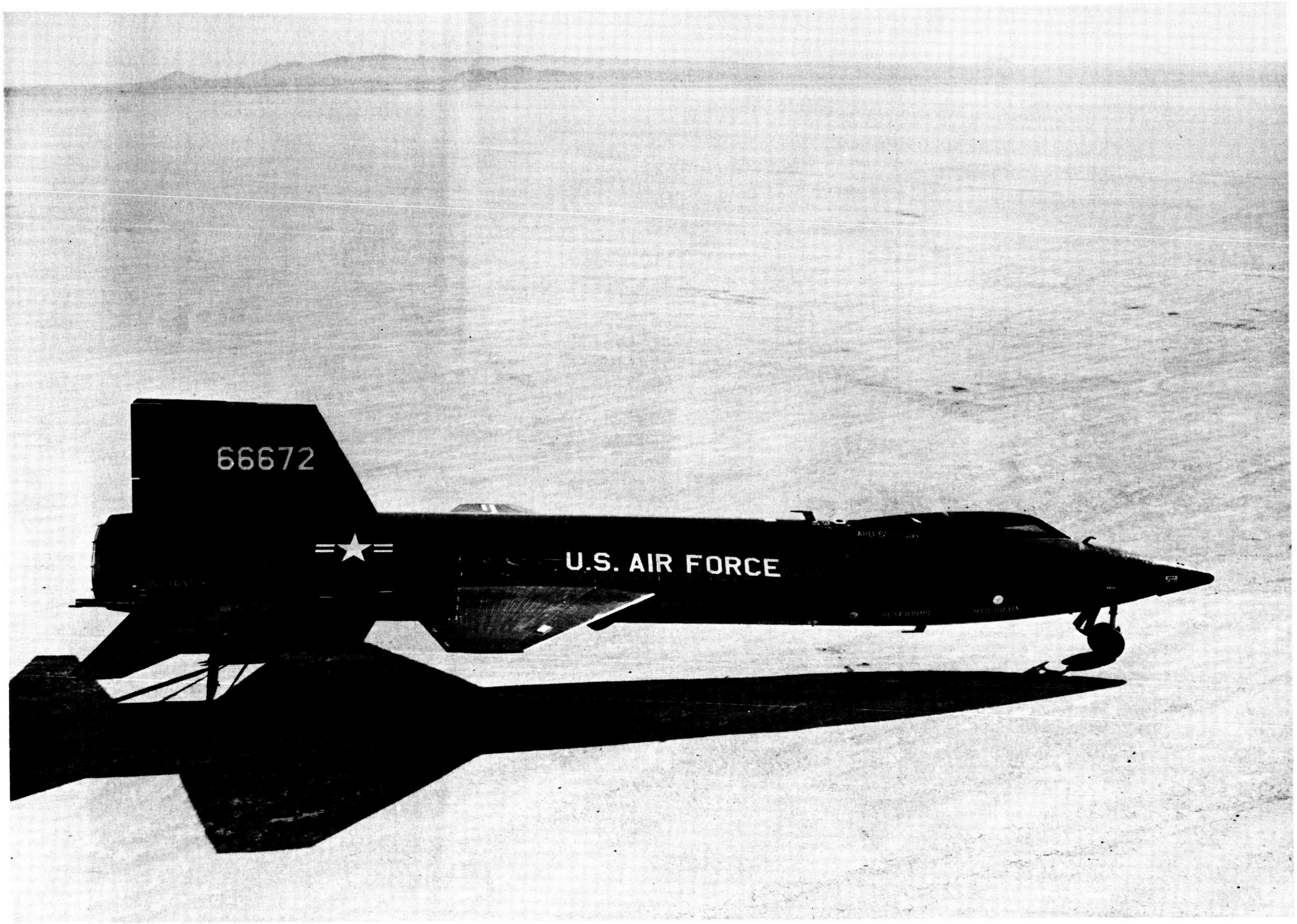
Flight number (a)	Pilot	Landing weight, lb	Wind conditions		Velocity at touchdown, KIAS	Vertical velocity, fps	True ground speed at touchdown, knots	Runway		Indicated angle of attack, deg	Pitch velocity, radians/sec	Roll velocity, radians/sec	Sideslip angle, deg	Flap angle, deg	Center-of-gravity acceleration, g
			Velocity, knots	Direction				Magnetic heading, deg	Condition						
3-1-2	G	14,723	Calm[b]	-----	181	2.0	176	180	Damp, hard	7.0	-----	0	1.8 (right)	28.6	1.02
3-2-3	G	14,303	Calm	-----	191	2.5	-----	180	Dry, hard	6.4	0.006 (down)	0	1.1 (right)	28.0	.95
3-3-7	G	14,307	Calm	-----	-----	2.5	-----	180	Dry, hard	-----	-----	-----	-----	-----	-----
3-4-8	G	14,286	12	North-northwest	165	7.3	-----	350	Hard, smooth	-----	-----	-----	-----	-----	-----
3-5-9	C	14,653	17	West	188	1.0	181	180	Dry, hard	9.6	.003 (down)	0.005 (left)	0	27.6	.20
3-6-10	C	14,553	Calm	-----	183	6.2	162	180	Dry, hard	5.4	.004 (down)	.01 (left)	2.0 (right)	28.4	.90
3-7-14	C	14,420	Calm	-----	198	3.0	201	180	Dry, hard	4.0	.021 (up)	0	1.6 (right)	28.1	1.20
3-8-16	B	14,558	-----	-----	189	-----	-----	180	Dry, hard	-----	.007 (up)	.005 (right)	.7 (right)	30.3	1.10
3-9-18	B	14,246	6	Southwest	183	4.0	-----	180	Dry, hard	5.8	.012 (up)	0	.9 (left)	27.6	1.01
3-10-19	F	14,492	13 to 22 gusts	-----	-----	6.8	-----	180	Dry	-----	.043 (up)	.007 (left)	1.1 (left)	32.4	.97
3-11-20	F	14,411	Calm	-----	212	.5	223	180	Dry, smooth	7.7	.002 (down)	0	.4 (right)	30.3	.84
3-12-22	C	14,491	-----	-----	188	.5	188	180	Dry, hard	11.5	.015 (up)	.12 (left)	0	27.4	1.18
3-13-23	B	14,562	Calm	-----	178	-----	192	180	Dry, hard	10.8	.008 (up)	.18 (right)	3.6 (right)	27.4	1.00
3-14-24	B	14,709	Calm	-----	190	2.0	202	180	Dry, hard	8.3	.008 (down)	.01 (left)	.1 (right)	27.0	1.05

[a]First term indicates X-15 airplane by number; second term indicates number of free flights for that airplane; third term indicates number of airplane X-15/B-52 missions for the airplane.

[b]"Calm" denotes variable from 0 to 3 knots.

[c]Emergency.

[d]Initial contact followed by rebound.



E-7905

Figure 1.- X-15 research airplane.

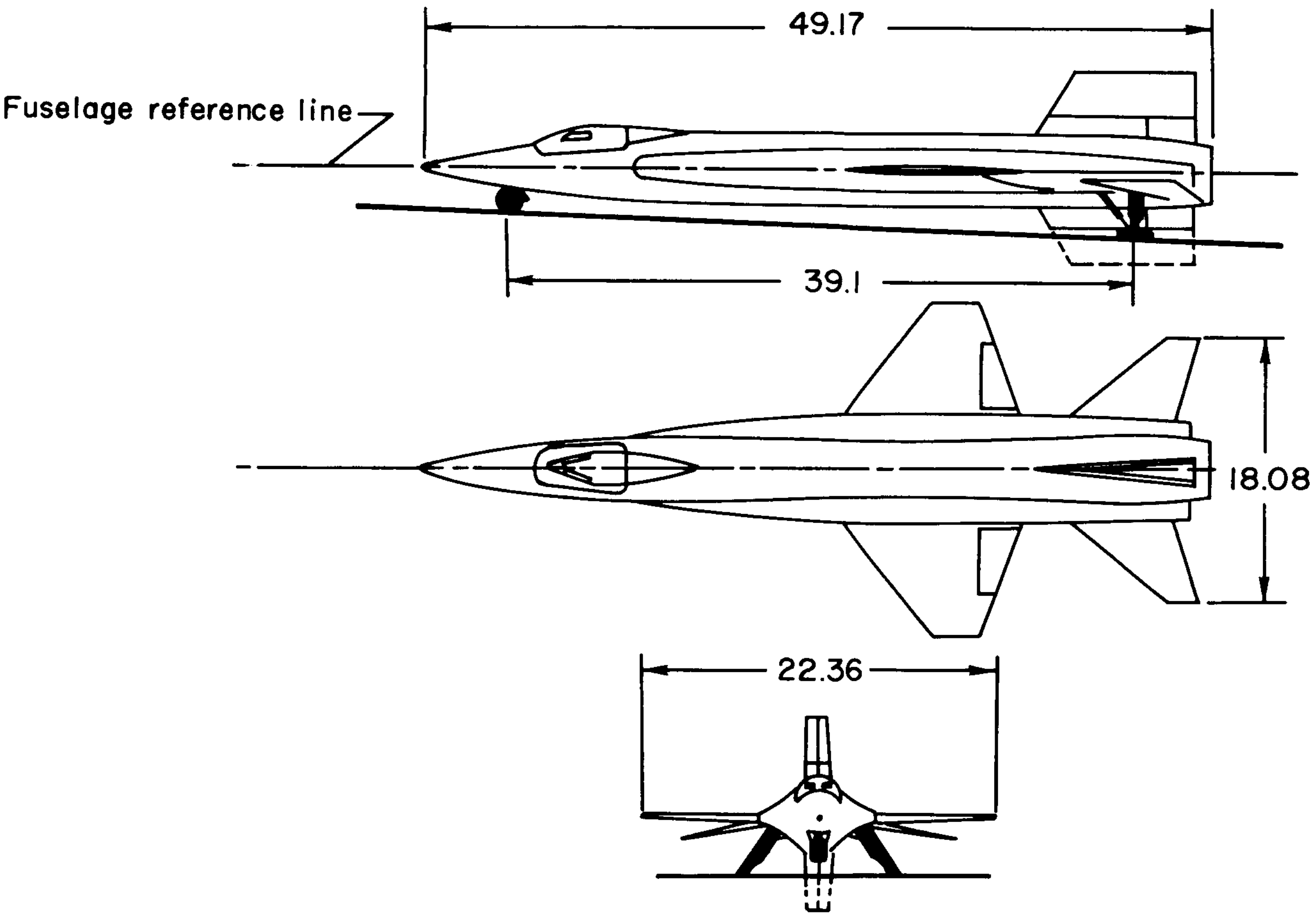


Figure 2.- Three-view drawing of the X-15 airplane. All dimensions in feet.

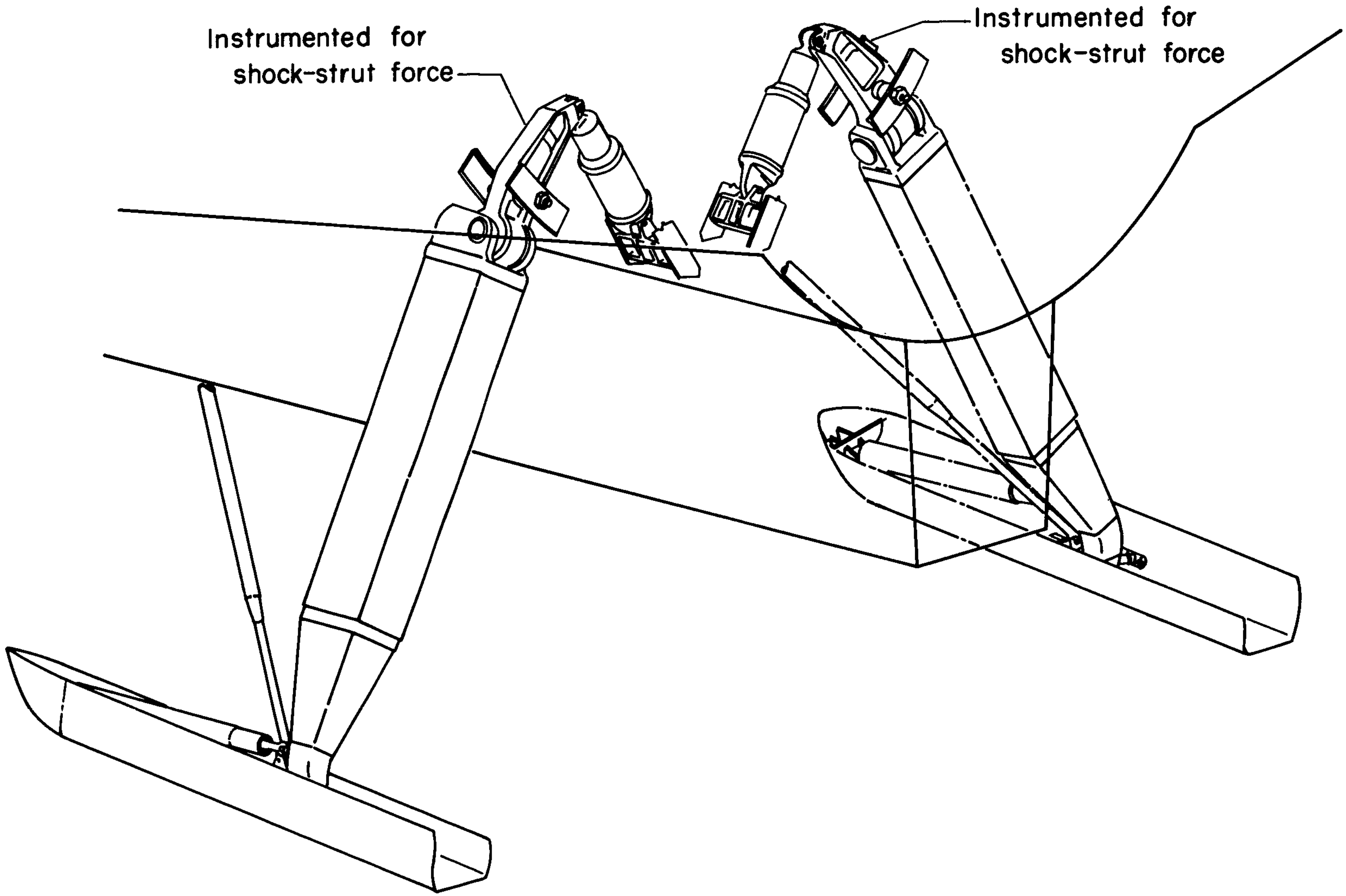


Figure 3.- Schematic drawing of the X-15 main landing gear.

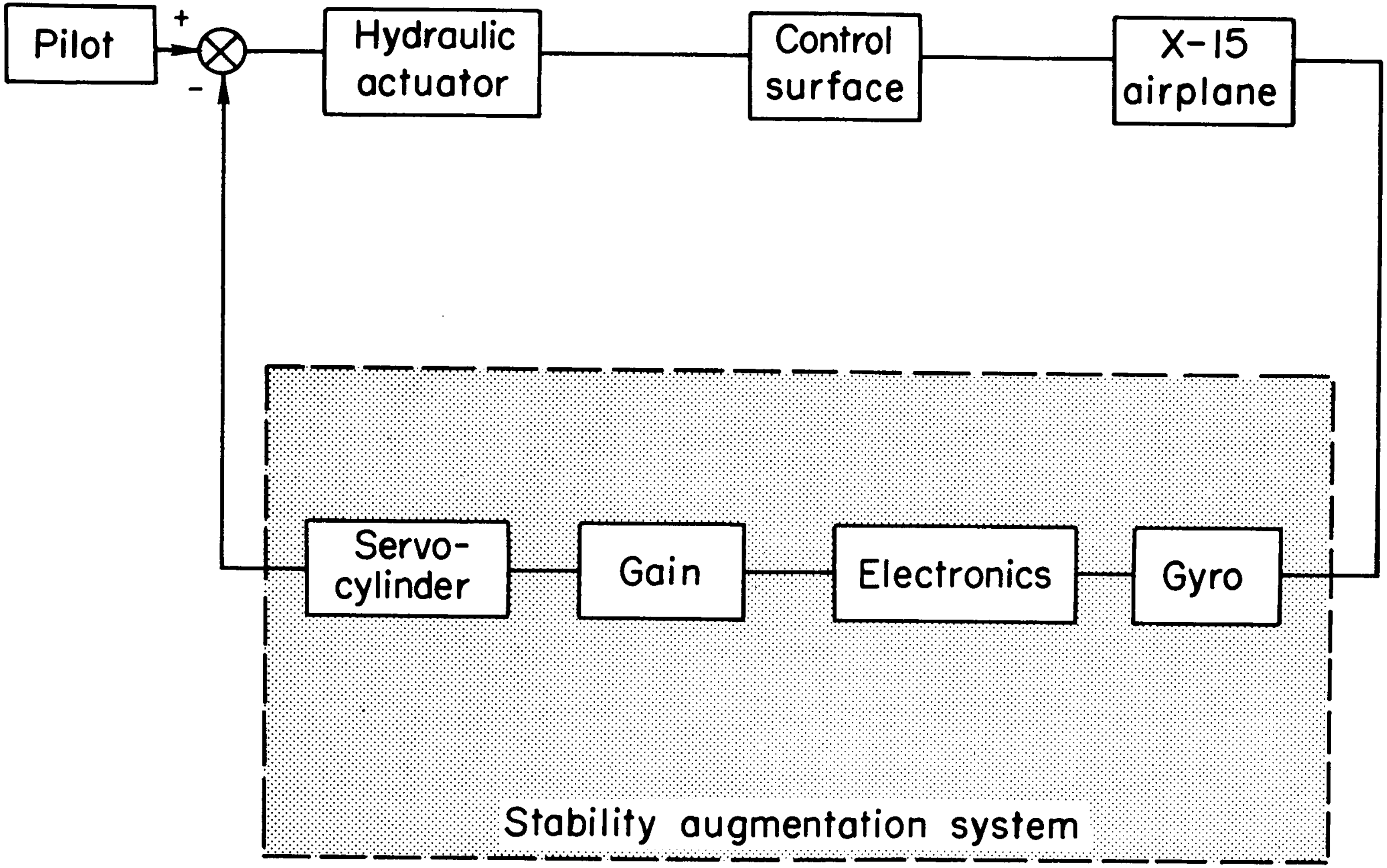


Figure 4.- Simplified block diagram showing components of stability augmentation system.

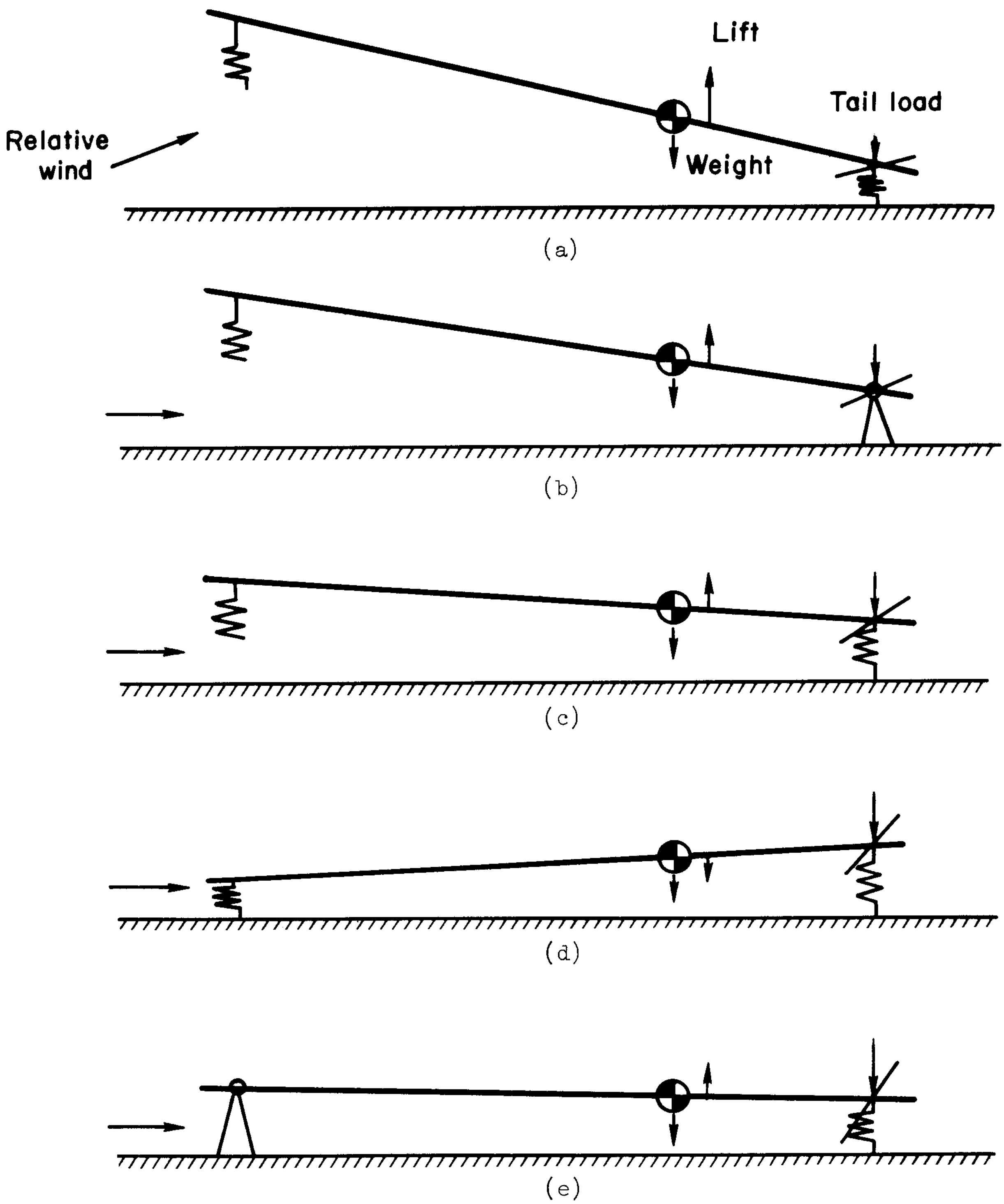


Figure 5.- X-15 landing sequence showing conditions leading to second main-gear reaction.

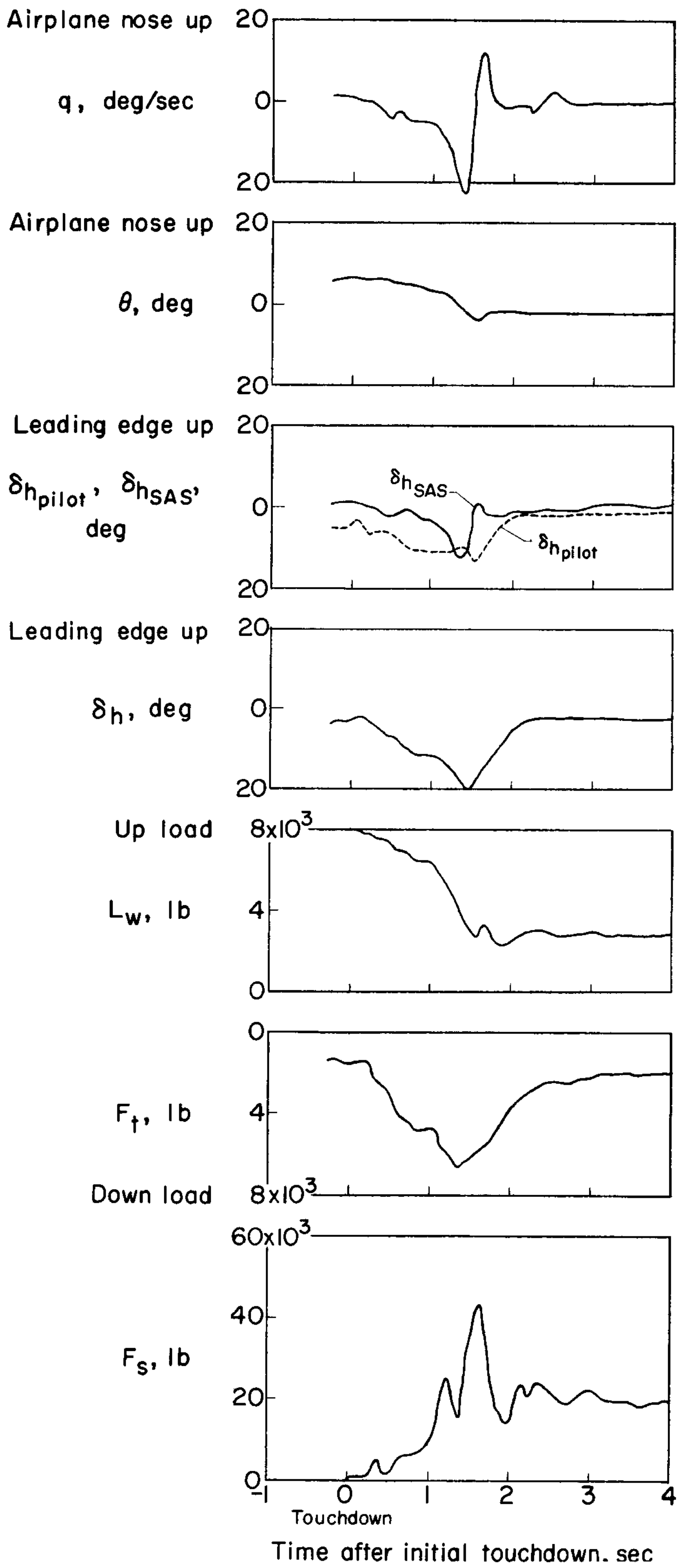


Figure 6.- Typical X-15 landing using wing flaps. Nose-gear touchdown at $\Delta t_n = 1.35$ sec (flight 1-30-51).

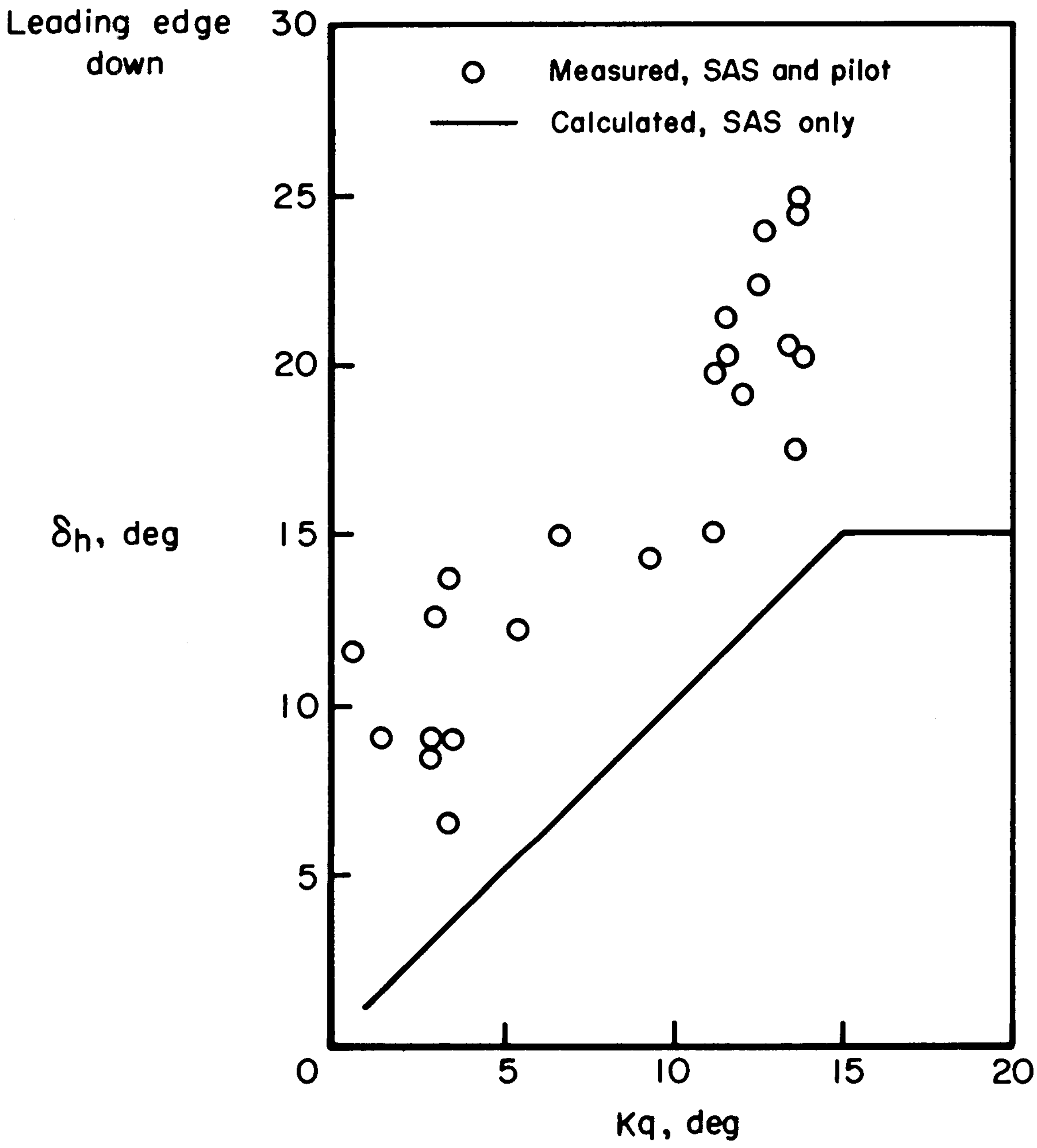


Figure 7.- Horizontal-stabilizer deflection as a function of SAS gain and pitch rate (trim $\delta_h = 0°$).

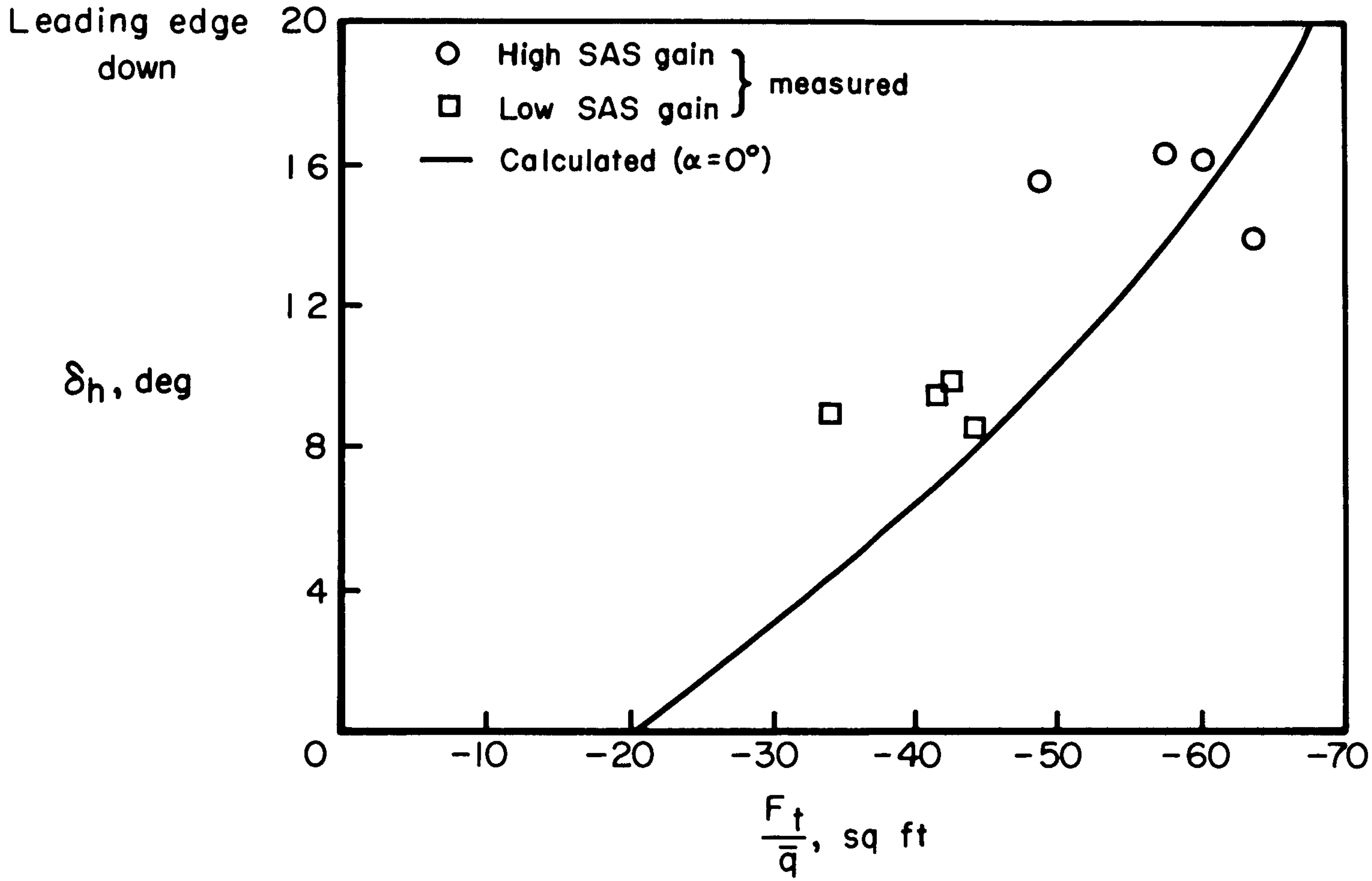


Figure 8.- Aerodynamic load on horizontal stabilizer as a function of stabilizer position.

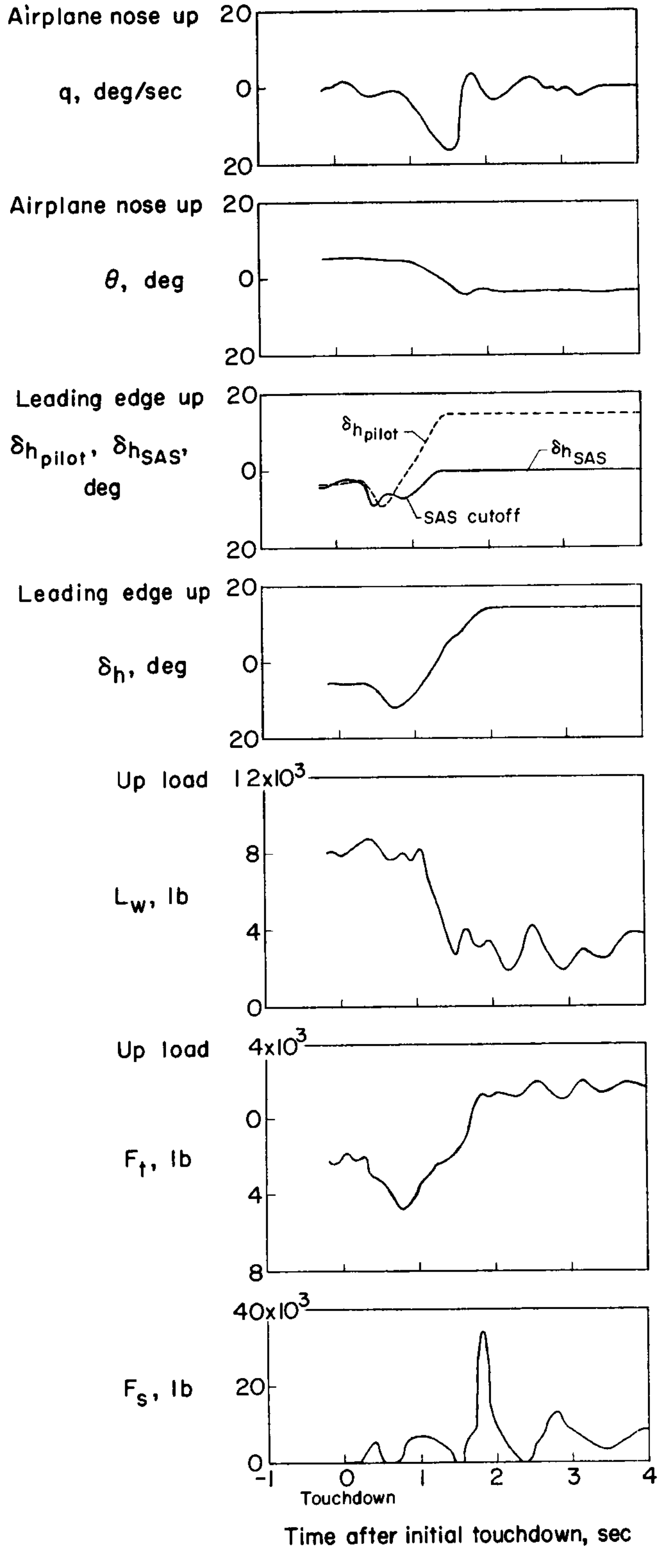
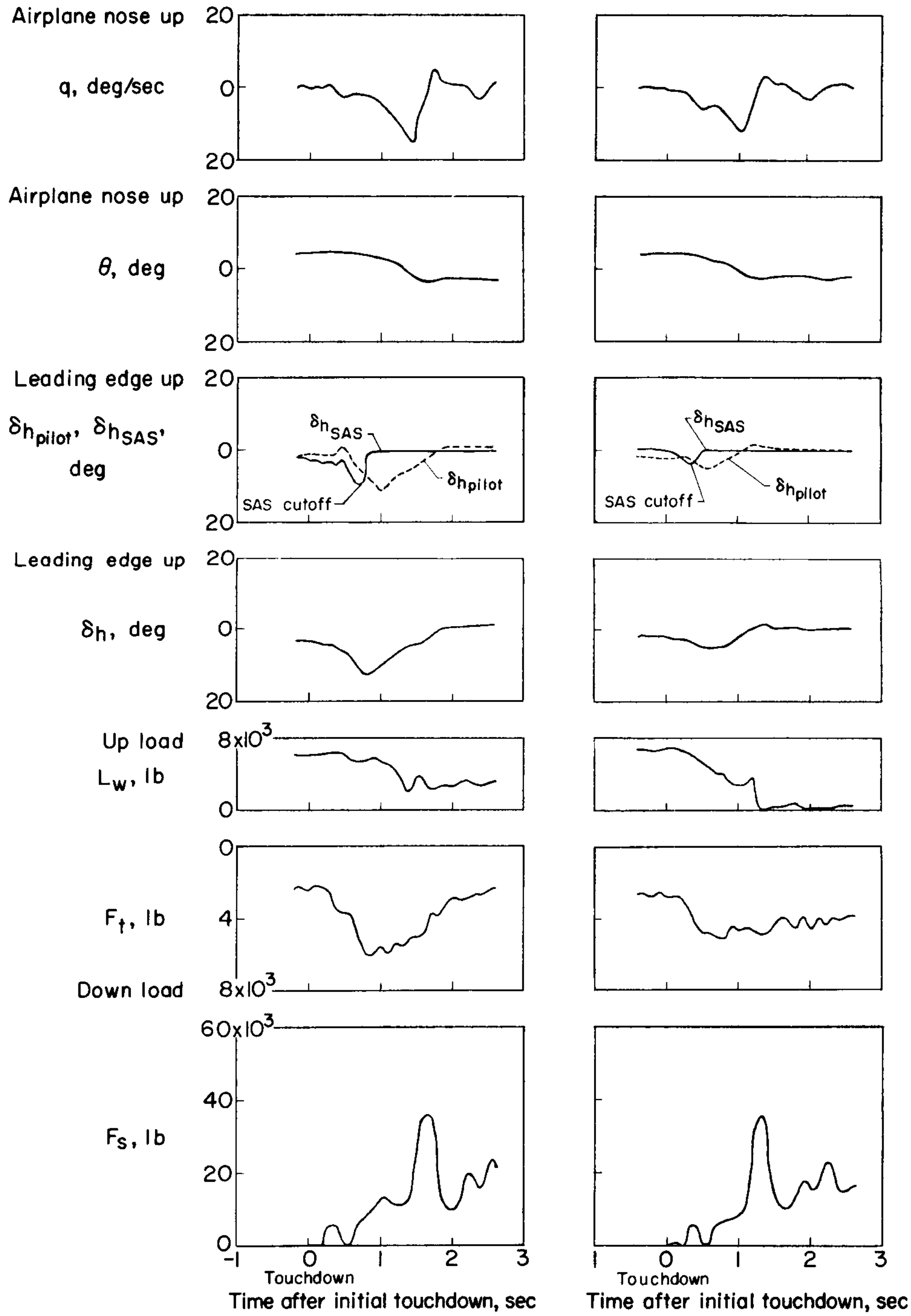


Figure 9.- X-15 landing in which horizontal-tail down loads were decreased by programing control inputs. Nose-gear touchdown at $\Delta t_n = 1.48$ sec (flight 3-12-22).



(a) First attempt. Nose-gear touchdown at $\Delta t_n = 1.41$ sec (flight 3-13-23).

(b) Second attempt. Nose-gear touchdown at $\Delta t_n = 1.03$ sec (flight 3-14-24).

Figure 10.- X-15 landing in which SAS automatically disengaged dampers and pilot released control stick after main-gear touchdown.

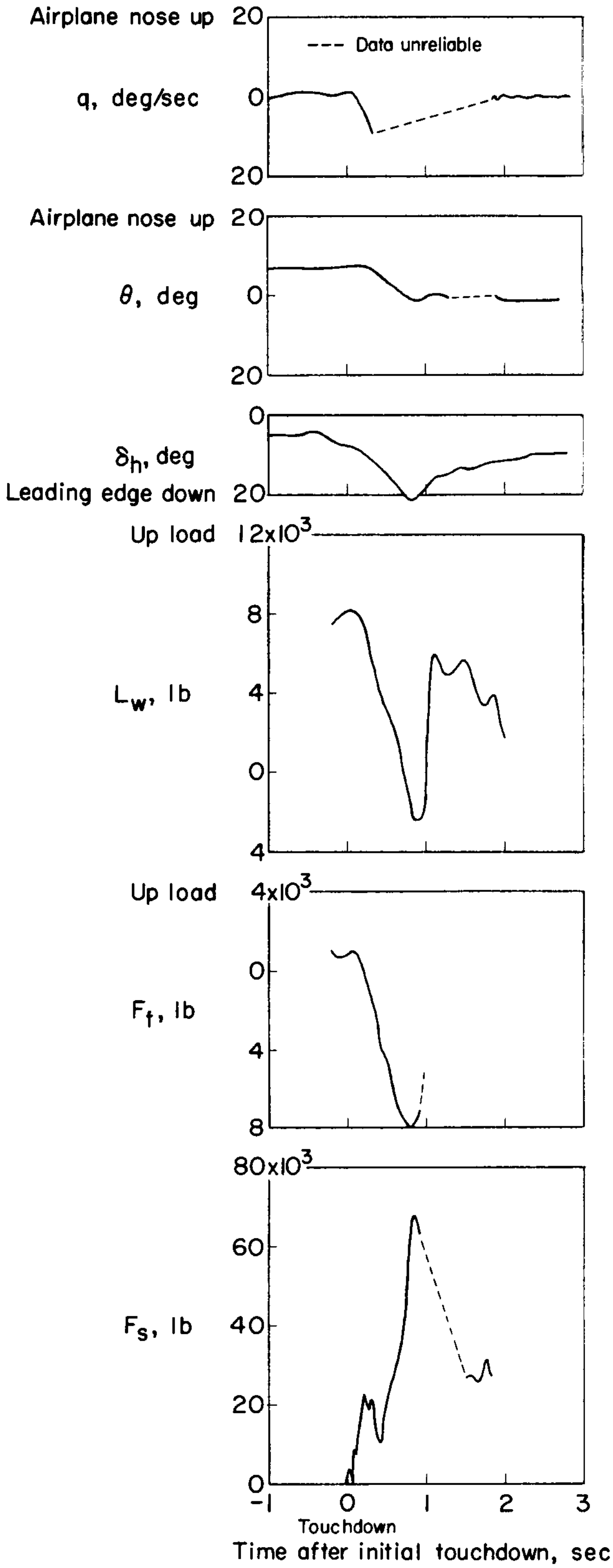


Figure 11.- X-15 landing performed without using wing flaps. Nose-gear touchdown at $\Delta t_n = 0.40$ sec (flight 2-31-52).

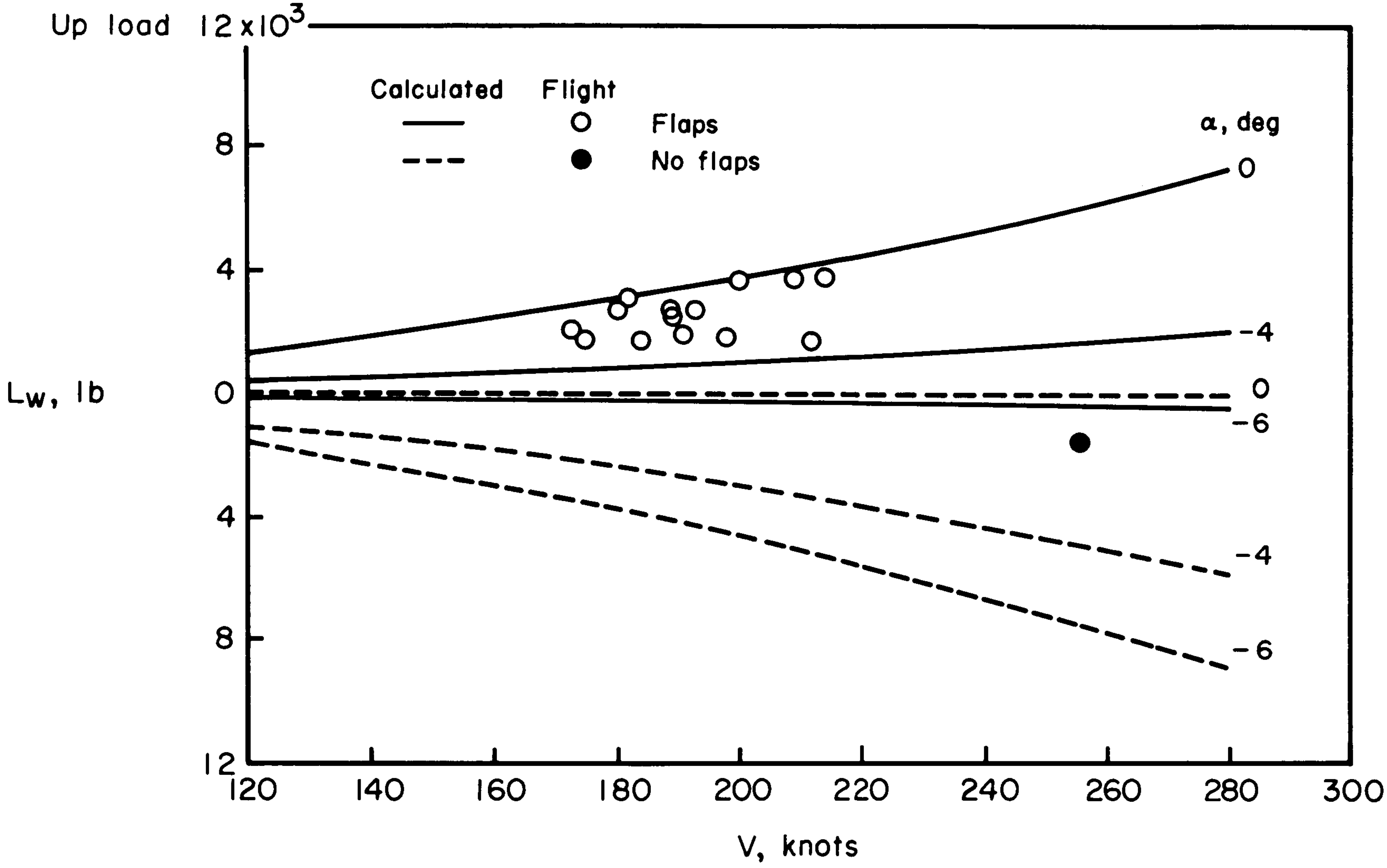


Figure 12.- Variation of wing lift at maximum main-gear load with touchdown velocity, showing the effect of flaps.

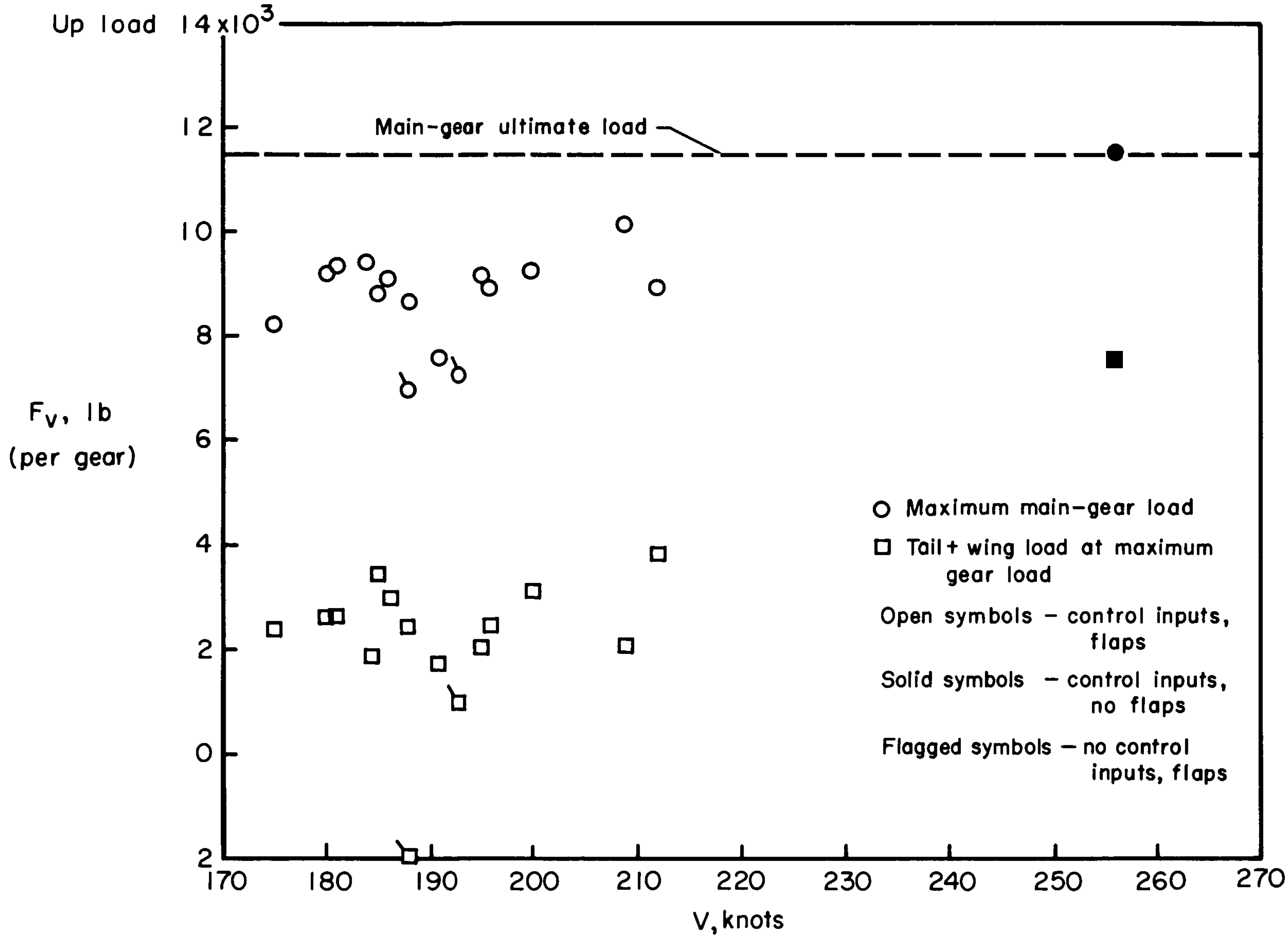


Figure 13.- Comparison of maximum main-gear loads with tail—wing loads.